MANUAL

OF

DETERMINATIVE MINERALOGY

WITH AN INTRODUCTION ON

BLOWPIPE ANALYSIS.

BY

GEORGE J. BRUSH,

Director of the Sheffield Scientific School of Yale University.

REVISED AND ENLARGED, WITH ENTIRELY NEW TABLES
FOR THE IDENTIFICATION OF MINERALS,

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of Yale University.*

SIXTEENTH EDITION, REVISED.

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PREFACE.

THE present work is a complete revision of the "Manual of Determinative Mineralogy and Blowpipe Analysis" by Prof. Geo. J. Brush, which has been very generally used since its first appearance in 1874, as shown by the fact that fourteen editions of it have appeared. In 1896 a revision of the introductory chapters devoted to blowpipe analysis and the chemical reactions of the elements was published, and there are now added a chapter on the physical properties of minerals, devoted chiefly to crystallography, and a new set of analytical tables for the identification of minerals.

In preparing the introductory chapters, great pains has been taken in the selection of the tests for the elements. Many of the experiments are performed by means of the blowpipe, but chemical tests in the wet way are recommended when it is believed that they are more decisive. All the tests have been carefully verified, and many of them have been devised especially for the present work. To make the book more convenient for reference, conspicuous headlines and catch-words have been freely used. The tests for the rare elements, and those for the common ones which are only occasionally employed, are printed in small type. It is hoped that the plan adopted of giving full directions concerning the methods of manipulation and the quantities of materials to be taken in making many of the tests will be found useful.

It must be borne in mind constantly that accuracy is of the utmost importance in determinative mineralogy, and it is believed that no methods are so generally to be relied upon for giving decisive results as those based upon the identification of the chemical constituents of the minerals. Moreover, most minerals can be identified by means of very simple tests, although some cannot be determined beyond question without resorting to the more elab-

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The author takes pleasure in expressing his obligations to his associates, Professors G. J. Brush, E. S. Dana, L. V. Pirsson, and H. L. Wells, for many valuable suggestions, and to the Misses L. P. and K. J. Bush of New Haven for services rendered in the preparation of the manuscript and in proof-reading. The woodcuts were prepared by the skillful engraver, Mr. W. F. Hopson of New Haven.

NEW HAVEN, October 1, 1898.

PREFACES OF THE FORMER EDITIONS OF THIS WORK, BY GEORGE J. BRUSH.

PREFACE TO THE FIRST EDITION.

THE material in this compilation was, for the greater part, prepared almost twenty years since, by Prof. S. W. Johnson and myself, as a text-book for the students in our laboratory. Circumstances prevented its publication at that time, but it has served as the basis of a course of lectures and practical exercises annually given in the Sheffield Laboratory.

The plan of instruction has been to have the student work through a course of Qualitative Blowpipe Analysis as introductory to Determinative Mineralogy. For the latter subject, we have employed VON KOBELL'S *Tafeln zur Bestimmung der Mineralien*, many of the students taking the work in the original, while others made use of either Erni's or Elderhorst's translations. These "Tables" were translated by Prof. Johnson and myself while we were students of Prof. von Kobell in 1853–4, at Munich, and it was after our suggestion, in 1860, to Prof. Elderhorst, that he introduced von Kobell's "Tables" into the second edition of his "Manual," although he did not avail himself of our translation, which was then offered to him for that purpose.

The "Tables" as now presented are based on the tenth German edition of von Kobell's book. Additions of new species have been made, and in many cases, fuller details are given in regard to old species, and the whole material has been thrown into an entirely new shape, which it is believed will greatly facilitate the work of the student. The preparation of the tables in this form, the idea of which was suggested to me by Prof. W. T. ROEPPER, has been performed, under my supervision, by my assistant, Mr. GEORGE W. HAWES, who has also aided me greatly in revising the rest of the work, and in the reading of the proof-sheets.

The main authorities used in the original preparation and later revision of the chapters on Blowpipe Analysis were the works of BERZELIUS and PLATTNER. The third and fourth editions of Plattner, the latter edited by Prof. RICHTER, have been chiefly consulted. The complete work of Plattner, with still later additions by Prof. Richter, has been made accessible to English-reading students through an excellent translation by Prof. H. B. CORNWALL, and this cannot be too highly commended to those who desire to become fully acquainted with this important subject.

In Determinative Mineralogy, besides the works of von Kobell, free use has been made of the treatises of NAUMANN and DANA, especially of the pyrognostic characters contributed by myself to the latter work. This constitutes, in accordance with the original plan of Professor Dana and myself, the Determinative Part of his System of Mineralogy. It is proposed at some future time to add to the volume methods for the determination of minerals by their physical characters.

In conclusion, I take great pleasure in acknowledging my indebtedness to my colleague, Prof. S. W. Johnson, who has not only generously given me his share in the original work, but has constantly aided me by his advice in the revision here presented.

SHEFFIELD LABORATORY OF YALE COLLEGE,
NEW HAVEN. December 15, 1874.

PREFACE TO THE THIRD AND LATER EDITIONS.

This edition has been so far revised as to substitute for the old formulas for minerals, those based upon the atomic weights of the elements adopted by the so-called new chemistry. The formulas for the most part have been taken from *Rammelsberg's Mineralchemie* (Leipzig, 1875), and are made to correspond as far as possible with those given in *Dr. E. S. Dana's Text-Book of Mineralogy* (John Wiley & Sons, New York, 1877).

It should be stated here that as the main object of this book is the identification of mineral species by a method largely based on the blowpipe characters of their elemental constituents, this point has been kept in view in writing their formulas. Instead of giving a symbol for a group of elements, as is usual in mineralogical treatises, it has been necessary to give the elements in full, and in some instances, for want of space, a simple list of the constituents is substituted for the formulas. This has also been done in the case of minerals where no satisfactory formulas have been deduced.

It has not been thought advisable to alter the old common names used for reagents and compounds, since the book is intended not only for students in colleges and schools, but for all the different classes of persons who are interested in the study of minerals.

A few changes and additions in the text of the tables are made, which, it is trusted, will facilitate the work of the student. My acknowledgments are again due to Mr. George W. Hawes for his coöperation in making these changes.

New Haven, May 1, 1878.

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DETERMINATIVE MINERALOGY AND BLOWPIPE ANALYSIS.

CHAPTER I.

INTRODUCTION AND CHEMICAL PRINCIPLES.

The Mineral Kingdom.—Natural products are commonly divided into three kingdoms,—*animal*, *vegetable*, and *mineral*. The latter includes those substances constituting or found in the crust of the earth and not those made through the agency of life. They are, therefore, frequently called *inorganic materials*. Among these, two classes are recognized, which are known as *minerals* and *rocks*.

Minerals.—These are definite chemical compounds occurring in the mineral kingdom. The following may serve as examples:

Pyrite, sulphide of iron, FeS_2.

Quartz, oxide of silicon, SiO_2.

Orthoclase, silicate of potassium and aluminium, $KAlSi_3O_8$.

Chemical formulae show the invariable composition of the minerals when pure, that of quartz, for example, indicating that 1 atom of silicon is in combination with 2 atoms of oxygen. It ought to be possible to express the composition of every mineral by a chemical formula, but there are some for which this cannot yet be done, owing to the fact that they have not been sufficiently investigated.

On examining minerals, it will be observed that they usually occur in definite geometrical shapes called crystals, when conditions favorable for the formation of crystals have prevailed.

Every distinct chemical compound occurring in inorganic nature, having a definite molecular structure or system of crystallization and well-defined physical properties, constitutes a mineral species. Up to the present time, between eight and nine hundred minerals, which deserve to rank as distinct species, have been recognized. Of these, however, only a few can be considered as common, and really important either as rock-forming minerals in making up the crust of the earth, or as ores of the useful metals, or as otherwise valuable in the arts. Each mineral species has received a name (usually ending in *ite*, signifying '*of the nature of*,' '*like*') by which it is commonly known. In assigning these names no system has been followed, some being derived from chemical, physical, or fanciful peculiarities, some from localities where the minerals were first found, while many are named after persons.

Rocks.—With the exception of a few glassy lavas, rocks are aggregates of mineral particles. The term *rock* is often used in a general way for designating any portion of the earth's crust, but the kinds of rock to which geologists have assigned special names contain certain minerals in about the same proportion throughout. Thus, granite is one of the commonest rocks of the globe, and, on examination, a fragment of it will be found to be made up of different minerals. The most conspicuous is orthoclase, $KAlSi_3O_8$, together with a corresponding soda mineral, albite, $NaAlSi_3O_8$, and quartz, SiO_2, while a number of others may be present in small amounts. The proportion of these minerals differs in different kinds of granite, and it is therefore evident that the composition of this rock cannot be expressed by a definite chemical formula.

In a rock, the structure may be coarse-grained, so that the particles can be detected with the naked eye, or fine-grained, rendering a microscope necessary to distinguish the different components. Usually a rock is composed of different minerals, but it sometimes consists of only one. Thus, marble is an aggregate of particles of calcite, $CaCO_3$, and quartzite of quartz, SiO_2. The study of rocks, known as lithology or petrography, necessitates a previous knowledge of mineralogy.

Chemistry.—Mineralogy is chiefly a chemical science, and for a proper understanding of minerals, some knowledge of elementary chemistry is indispensable. A brief summary, therefore, of some important chemical principles will be first given. By a careful study of the experimental part of the following chapters, it is believed that much useful information concerning general elementary chemistry may be gained.

Elements.—A substance which cannot be separated into simpler constituents is regarded as an *element.* At the present time, about 70 elements are recognized. Of these, less than half are of common occurrence, while, from a consideration of a large number of rock analyses, F. W. Clarke* has calculated that 99 per cent of the solid crust of the earth, for a depth of ten miles, is composed of the following eight elements:

Oxygen,	47.3%	Calcium,	3.8%
Silicon,	27.2	Magnesium,	2.7
Aluminium,	7.8	Sodium,	2.4
Iron,	5.4	Potassium,	2.4

Chemical Affinity, Atoms, and Molecules.—Elements manifest tendencies to unite with one another. This property is known as *chemical affinity.* It is usually strongest between metallic and non-metallic elements; as sodium and chlorine in sodium chloride. The smallest particle of an element which enters into combination is called an *atom*, and the smallest particle of a chemical compound which is capable of existence is called a *molecule.*

Symbols.—For convenience, elements are designated by symbols, usually the initial letter of their names, or this with one other letter. Each symbol stands for one atom of the element; as S for sulphur, Pb for lead (Latin *plumbum*). PbS is the chemical formula of, and represents a *molecule* of, lead sulphide.

Law of Definite Proportion.—Atoms unite with one another in definite, though frequently in two or more different, proportions.

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*Phil. Soc. of Washington, Bull. IX., p. 138, 1889.

For example, carbon, sulphur, and arsenic, each form two distinct oxides, CO and CO_2, SO_2 and SO_3, As_2O_3 and As_2O_5.

Valence.—This term is used to express the numerical proportion in which elements unite with or replace hydrogen. Chlorine is *univalent* and oxygen *bivalent*, because they unite with hydrogen to form the molecules HCl and H_2O, respectively. The term valence is also applied to compounds. Thus, sulphuric acid being H_2SO_4, the radical SO_4 is said to be *bivalent.*

Acids.—Compounds resulting from the union of non-metallic elements, with hydrogen or hydrogen and oxygen, in which the hydrogen atoms may be replaced by metals, are called *acids.* These usually possess a sharp, sour taste and have the property of turning blue litmus-paper red. The common mineral-forming acids are hydrochloric, HCl; nitric, HNO_3; hydrofluoric, HF; hydrogen sulphide, H_2S; sulphuric, H_2SO_4; carbonic, H_2CO_3; boric, H_3BO_3; phosphoric, H_3PO_4; arsenic, H_3AsO_4; orthosilicic, H_4SiO_4; metasilicic, $H_4Si_2O_6$, and polysilicic, $H_4Si_3O_8$. In the foregoing formulae, the groups of elements with which the hydrogen atoms are united are often called *acid radicals.* Thus, SO_4 is the acid radical of sulphuric acid; PO_4 of phosphoric; SiO_4 of orthosilicic, etc.

Bases.—Combinations of metals with oxygen and hydrogen (the hydroxides; for example, $NaOH$, sodium hydroxide) are called *bases.* These have the property of neutralizing acids, and, if soluble in water, of turning red litmus-paper blue. The combinations of metals with oxygen are sometimes called *basic oxides.*

Salts.—Compounds formed by the combination of acids and bases, and resulting in the replacement of part or all of the hydrogen atoms of the acid by metals, are called *salts.* The great majority of minerals are salts, and in a natural chemical classification they are subdivided into groups according to the acid radicals which they contain; i.e., the sulphides, salts of hydrogen sulphide, in one group; the sulphates, salts of sulphuric acid, in another; the silicates, salts of silicic acid, in a third, etc.

With a knowledge of the valence of a given metal, it is a simple matter to write the normal salt of any known acid, as shown by the following table:

	Hydrochloric, HCl.	Sulphuric, H_2SO_4.	Phosphoric, H_3PO_4.	Orthosilicic, H_4SiO_4.
Sodium, Na, *univalent*,	$NaCl$	Na_2SO_4	Na_3PO_4	Na_4SiO_4
Calcium, Ca, *bivalent*,	$CaCl_2$	$CaSO_4$	$Ca_3(PO_4)_2$	Ca_2SiO_4
Ferric iron, Fe, *trivalent*,	$FeCl_3$	$Fe_2(SO_4)_3$	$FePO_4$	$Fe_4(SiO_4)_3$

Chemical Equations.—When chemical substances react upon or unite with one another, definite transformations take place, which can be expressed in the form of equations. Thus, when calcite is dissolved in hydrochloric acid, or barite is fused with sodium carbonate, the results are shown as follows:

$$CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2.$$
$$BaSO_4 + Na_2CO_3 = BaCO_3 + Na_2SO_4.$$

The practice of writing correct equations serves a useful purpose in affording a knowledge of the manner in which chemical reactions take place.

Atomic Weight.—It has been found that an atom of an element possesses a definite relative weight, known as its *atomic weight.* This is based on an atom of hydrogen, the lightest of all elements, as a standard (the weight of the hydrogen atom being taken as 1). The atomic weights of the common elements have been very accurately determined and are generally given with their descriptions.

Molecular Weight.—The *molecular weight* of a substance is equal to the sum of the atomic weights of the elements constituting the molecule. Thus, calcium, carbon, and oxygen, having the atomic weights 40, 12, and 16, respectively, $CaCO_3$ has a *molecular weight* of $40 + 12 + 48 = 100$.

Relations between Chemical Formulae and Percentage Composition.—With a knowledge of the chemical formula of a compound and of the atomic weights, the percentage composition of the different constituents can be readily calculated. For example, sphalerite is ZnS. The atomic weights are $Zn = 65.4$ and

S = 32, hence the molecular weight of ZnS is 97.4. In 97.4 parts by weight of ZnS there are 65.4 parts of zinc, consequently the zinc in 100 parts may be readily calculated by a simple proportion, thus: $97.4 : 65.4 = 100 : x$, which gives 67.1 as the per cent of zinc.

It is often convenient to give the percentages of combinations of the elements, especially the oxides, instead of the elements themselves. This is illustrated by the following examples, where the percentages are derived from the molecular weights by the proportion, Total Mol. Wt. : Mol. Wt. of constituent = 100 : *x:*

Andradite Garnet.

$Ca_3Fe_2Si_3O_{12} = 3CaO.Fe_2O_3.3SiO_2$.

	At.Wt.		Mol.Wt.		
Si,	28	× 3 =	180	SiO_2,	35.4%
O_2,	32				
Fe_2,	112		160	Fe_2O_3,	31.5
O_3,	48				
Ca,		× 3 =	168	CaO,	33.1
O,					
			508		100.0

Dolomite.

$CaMg(CO_3)_2 = CaCO_3.MgCO_3$.

	At.Wt.	Mol.Wt.		
Ca,	40	100	$CaCO_3$,	54.3%
C,	12			
O_3,	48			
Mg,	24	84	$MgCO_3$,	45.7
C,	12			
O_3,	48			
		184		100.0

Quantitative Chemical Analyses.—The chemical composition of minerals is determined by means of quantitative analyses, and many of these will be found recorded in the larger treatises on mineralogy. Now, since a percentage analysis gives the weights of the different constituents in one hundred parts, and each constituent has its definite relative weight (atomic or molecular), therefore the *relative number* of atoms or molecules may be found by dividing the percentages by their atomic or molecular weights. The quotients indicate the *ratio* of the constituents, which is usually a simple one.

The following examples of actual analyses will illustrate this:

Sphalerite.

	Found.		At.Wt.		Ratio.
S,	32.93	÷	32	=	1.029
Zn,	66.69	÷	65.4	=	1.019
Fe,	.42				
	100.04				

Andradite Garnet.

	Found.		Mol.Wt.		Ratio.
SiO_2,	35.44	÷	60	=	.591
Fe_2O_3,	31.85	÷	160	=	.199
CaO,	32.85	÷	56	=	.587
MgO,	.20				
	100.34				

The ratios derived from these analyses are as follows:

S : Zn = 1.029 : 1.019 = 1.00 : 0.99, or very nearly 1 : 1.

$SiO_2 : Fe_2O_3 : CaO$ = .591 : .199 : .587 = 2.95 : 1.00 : 2.97, or nearly 3 : 1 : 3.

The formula of sphalerite is, therefore, ZnS, and that of the garnet, $3CaO.Fe_2O_3.3SiO_2$, or $Ca_3Fe_2Si_3O_{12}$. These analyses may be compared with the theoretical values calculated in the previous paragraphs.

Isomorphism (*ἴσος*, equal, + *μορφή*, form).—Substances which are analogous in chemical composition frequently show a similarity in crystallization. This is known as *isomorphism.* Thus, the alums, $KAl(SO_4)_2.12H_2O$, and $(NH_4)Al(SO_4)_2.12H_2O$, are isomorphous. They must have similarity in molecular arrangement, for they not only crystallize in the same shapes, but, from a solution containing both salts, a crystal may be grown consisting partly of potash and partly of ammonia alum. This tendency of two salts to crystallize together constitutes the strongest proof of their isomorphism.

Isomorphism plays a very important part in mineralogy. Many species are mixtures of two or more isomorphous chemical molecules, and, owing to this fact, the physical properties (especially color, specific gravity, and fusibility) are often found to vary widely. For example, sphalerite when it has the composition ZnS is colorless or nearly so. It usually, however, contains isomorphous FeS, and the color becomes darker as the percentage of iron sulphide increases. Columbite, $FeNb_2O_6$, and the isomorphous tantalite, $FeTa_2O_6$, have the specific gravities 5.3 and 8.2, respectively; while intermediate mixtures of the two molecules have specific gravities ranging between these values.

Concerning isomorphous mixtures, it is often stated that one element *replaces* the other; i.e., sphalerite is ZnS, but part of the zinc may be replaced by iron. To express the composition of these mixed compounds, two methods are commonly employed; either the isomorphous elements are designated by some symbol, as R, or they are enclosed in parentheses. For example, sphalerite is said to have the composition RS, where R = Zn and Fe, or (Zn,Fe)S, giving importance to the prevailing constituent by placing it first, and often, also, by using larger type. By the latter formula, it is not meant that sphalerite contains one atom of zinc, one of iron, and one of sulphur, but that the zinc and iron taken together are equivalent to one atom of a bivalent metal.

The following examples will illustrate the methods of deriving formulae from analyses of isomorphous compounds:

I.
Brown Sphalerite.
Roxbury, Conn.

	Found.	At.Wt.	Ratio.
S,	33.36 ÷	32	= 1.043
Zn,	63.36 ÷	65.4	= .969
Fe,	3.60 ÷	56	= .064
	100.32		

II.
Black Sphalerite.
Felsöbánya.

	Found.	At.Wt.	Ratio.
S,	33.25 ÷	32	= 1.039
Zn,	50.02 ÷	65.4	= .756
Fe,	15.44 ÷	56	= .276
Cd,	.30 ÷	112	= .003
Pb,	1.01 ÷	207	= .005
	100.02		

III.
Almandine Garnet.
Fort Wrangel, Alaska.

	Found.	Mol.Wt.	Ratio.
SiO_2,	39.29 ÷	60	= .655
Al_2O_3,	21.70 ÷	102	= .213
FeO,	30.82 ÷	72	= .428
MnO,	1.51 ÷	71	= .021
MgO,	5.26 ÷	40	= .131
CaO,	1.99 ÷	56	= .036
	100.57		

In I, the ratio of S : Zn + Fe = 1.043 : 1.033 = 1.00 : 0.99 or almost exactly 1 : 1. The formula is therefore (Zn,Fe)S. The ratio of Zn : Fe = .969 : .064 or approximately 15 : 1, and the composition of the mineral may be regarded more exactly as 15ZnS + FeS.

In II, the ratio of S : Zn + Fe + Cd + Pb = 1.039 : 1.040 or 1 : 1. The formula is therefore (Zn,Fe,Cd,Pb)S, or, since Zn : Fe = .756 : .276 or nearly 11 : 4, the composition is more exactly 11ZnS + 4FeS + traces of CdS and PbS.

In III, FeO, MnO, MgO, and CaO are isomorphous and will be regarded as RO. The ratio of $SiO_2 : Al_2O_3 : RO = .655 : .213 : .616 = 3.07 : 1.00 : 2.89$. The ratio approximates to 3 : 1 : 3, and the formula is $3RO.Al_2O_3.3SiO_2$, or $R_3Al_2Si_3O_{12}$, where R = Fe, Mg, Ca, and Mn.

Dimorphism and Trimorphism.—Minerals which have the same percentage composition, but occur in two essentially different crystalline forms, are said to be *dimorphous*. Thus, carbon crystallizes in the isometric system as diamond, which is hard and transparent, with specific gravity $= 3.52$; and in the hexagonal system as graphite, which is soft and opaque, with Sp. Gr. $= 2.15$. Calcium carbonate, $CaCO_3$, crystallized in the hexagonal system, Sp. Gr. $= 2.71$, is calcite; and in the orthorhombic system, Sp. Gr. $= 2.94$, it is aragonite. Iron sulphide, FeS_2, crystallized in the isometric system, Sp. Gr. $= 5.02$, is pyrite, and in the orthorhombic system, Sp. Gr. $= 4.90$, it is marcasite. Titanic oxide, TiO_2, crystallizes in two entirely independent modifications in the tetragonal system, with Sp. Gr. $= 4.20$, as rutile, and with Sp. Gr. $= 3.90$, as octahedrite, and also in the orthorhombic system, Sp. Gr. $= 4.0$, as brookite. The last case, where three independent modifications of TiO_2 occur, is an example of *trimorphism*. Dimorphism and trimorphism may be due either to variations in the number of atoms, to variations in the arrangement of the latter in the chemical molecule, or to variations in the arrangement of the particles in the structure of the crystal. No exact means for determining the size of the chemical molecule in solid substances exists at present. TiO_2, for example, is the simple empirical formula for rutile, but its true composition is undoubtedly some multiple of TiO_2.

CHAPTER II.

APPARATUS AND REAGENTS, AND THE PRINCIPLES INVOLVED IN THEIR USE.

PART 1. APPARATUS.

Although a great deal of blowpipe apparatus has been devised, only that will be described in the present work which is necessary or convenient for making the simple tests for the identification of the elements and the determination of minerals. In performing most of the experiments a simple and inexpensive outfit will suffice, which, if necessary, can be packed in small space, so as to be portable. Moreover, a little ingenuity will often enable one to supply the place of much apparatus.

The Mouth-Blowpipe.—This instrument, for centuries employed only by artisans in soldering and in other operations requiring an intense heat, has been for a period of considerably over one hundred years an invaluable means of scientific research.* It is of the greatest service to the mineralogist and chemist for the identification of minerals and the detection of their ingredients, and may even be used for the *quantitative* separation of several metals from their ores.†

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* For a brief history of the use of the blowpipe, see Berzelius's work, *Die Anwendung des Löthrohrs;* or the translation by J. D. Whitney, Boston, 1845. A more complete history is found in Kopp's *Geschichte der Chemie*, II, p. 44, Braunschweig, 1844, and also in von Kobell's *Geschichte der Mineralogie*, München, 1864.

† Quantitative blowpipe analysis is beyond the scope of the present work. Those interested in Plattner's methods of assaying ores of gold, silver, copper, lead, cobalt, nickel, iron, etc., by means of the blowpipe, are referred to his work, *Probirkunst mit dem Löthrohre;* German edition, by Th. Richter; American translation, by H. B. Cornwall.

With no other fuel than that furnished by a common lamp or candle, the blowpipe renders it possible to produce in a moment a most intense heat. In the blowpipe flame, not only are many refractory bodies melted or volatilized, but entirely opposite chemical effects, *oxidation* and *reduction*, may be produced. Almost all chemical substances may be made to manifest some characteristic phenomena under its influence, either alone or in the presence of certain other substances known as reagents, and thus their nature may be detected.

The blowpipe is represented in its usual form in Fig. 1. The parts *a* and *b* fit into the chamber *c* with ground joints. Any moisture from the breath which condenses in *a* collects in *c*, and may be removed by disjointing the parts. The instrument is also furnished with a tip or jet (the most important part), which fits on *b* by means of a ground joint, and is shown at *d* in correct proportion and twice the natural size. The hole at the end of the tip should be slightly tapering and from 0.4 to 0.6 mm. in diameter. It should be bored in such a manner that its axis is in line with the axis of the tube *b* when the parts are fitted together. Very durable and inexpensive tips are made of brass. Those bored and turned out from solid platinum are expensive and scarcely better than brass, while light ones spun from platinum foil are unsatisfactory. Tips are very apt to become stopped with dust or foreign matter, and new ones often contain bits of metal turnings, or need to be reamed out to the proper size and taper. Cleaning and adjusting can best be accomplished by means of a four-sided, slightly tapering reamer, which may be made by filing down the sides of a large steel needle or pin. For the successful working of the blowpipe, it is also important that the

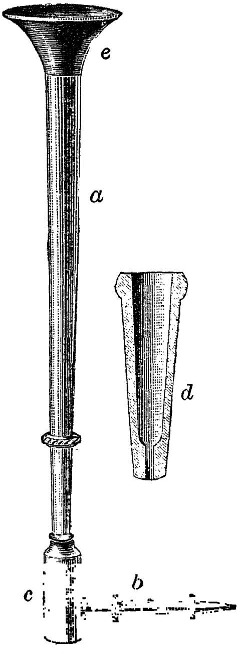

FIG. 1.

hole through *b* should not be eccentric, and that there should be nothing to disturb the passage of air.

The instrument as shown in Fig. 1, but without the trumpet mouthpiece, is of the original form proposed in the last century by Gahn, and employed by Berzelius. Fatigue is apt to result in using it, as considerable effort is required to keep the lips closed about the tube for any length of time.

Fig. 1 represents the blowpipe provided with the trumpet mouthpiece, *e*, recommended by Plattner. This is made of horn or hard rubber, 35 mm. in its outer diameter, and should have such a curvature that, when placed against the lips, it does not give an unnecessary or unequal pressure.

A very good mouthpiece may be made from a piece of glass tubing 5 cm. long, and of such diameter as fits the blowpipe tube. It should first be strongly heated for half its length in the flame of a lamp, and when quite soft flattened between two smooth metallic surfaces, to give it the form shown in Fig. 2. The other end should then be cemented into the blowpipe by means of sealing-wax. This kind of mouthpiece, when inserted between the lips, displaces them but slightly from their customary position, and causes very little fatigue.

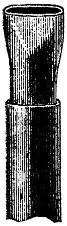

FIG. 2.

The blowpipe is usually made of brass, or preferably of German silver. The length of the instrument should be measured by the visual distance of the operator, the ordinary length being from 20 to 22 cm., exclusive of the mouthpiece.

The common, artisan's blowpipe, Fig. 3, consists of a tapering and curved tube of brass, terminating in an orifice as large as a small needle. When well constructed, this simple instrument answers most purposes, and is often made without the bulb near the bend, which is intended to collect the moisture condensing from the breath.

A great deal of ingenuity has been expended in devising different forms of blowpipes and mouthpieces, each supposed to have some special feature either of excellence or of cheapness to recommend it. However, if the blowpipe has a good tip, the form is of little importance, provided the operator is skilful and has become accustomed to the use of his instrument.

Blowing.—In blowpipe operations it is often necessary to maintain an uninterrupted stream of air for several successive minutes. To be able to do this easily requires some practice. It is best learned by fully distending the cheeks, closing the communication between the mouth-cavity and windpipe by means of the palate, and breathing through the nose. When one is accustomed to keeping the cheeks thus inflated, the mouthpiece of the blowpipe may be pressed against or inserted between the lips, and the same thing repeated without attempting to blow or do more than keep the cheeks distended. To the experienced operator, continuous blowing is hardly an effort.*

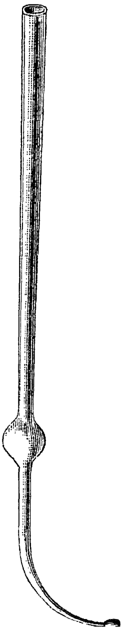

Fig. 3.

Fuel and Lamps.—The most convenient combustible is ordinary illuminating-gas burned in a Bunsen burner, Fig. 4. The gas issues from a small orifice near the lower end of the tube, and mixes with a large proportion of air which enters through holes at *h*. Usually the lamp is provided with a ring at *h*, fitting loosely over *d*, and by turning this the supply of air can be varied. The mixture of gas and air should be so regulated that the burner gives a non-luminous, blue flame, with a distinctly outlined inner cone about 5 cm. high. For use with the blowpipe, an additional

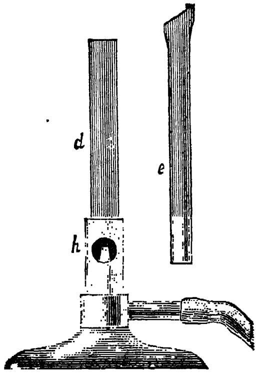

Fig. 4.

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* Various mechanical contrivances have been devised where the air is supplied from bellows, but they are regarded as unnecessary. The strength of the blast needs to be often varied in order to bring about different effects, and with the breath this can be most readily accomplished. Only students showing enterprise and patience sufficient to master the use of ordinary instruments will be likely to make much progress in blowpipe analysis.

tube, *e*, is supplied, which fits loosely inside of *d*, and goes down below the holes at *h*, thus cutting off the supply of air, and causing the gas to burn with a luminous flame. The tube is flattened at the top, and one side is made a little lower than the other, so that the blowpipe flame can be directed downward when necessary. A slightly raised notch at the upper side serves as a rest for the blowpipe tip.

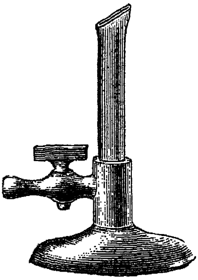
Fig. 5.

A burner like the one shown in Fig. 5 is convenient, but as it gives only a luminous flame it is not suitable for heating glass tubes, etc., and an additional Bunsen burner is necessary.

When gas is not at hand, olive- or rape-oil, burned in a lamp with a rectangular wick, 5 × 10 mm. in diameter, may be used. Fig. 6 represents the form of lamp proposed by Berzelius and improved by Plattner. The openings for the wick and for the admission of oil are provided with close-fitting screw-caps, and the apparatus can be taken apart and packed in small space for transportation.

Fig. 7 represents a lamp made by the Buffalo Dental Manufacturing Co., which gives satisfactory results.

A form of lamp adapted for portable blowpipe apparatus is represented in Fig. 8. Paraffin is used as fuel, and must be melted before lighting, but, when once ignited, the heat from the flame will keep a sufficient quantity of the paraffin in a liquid condition.

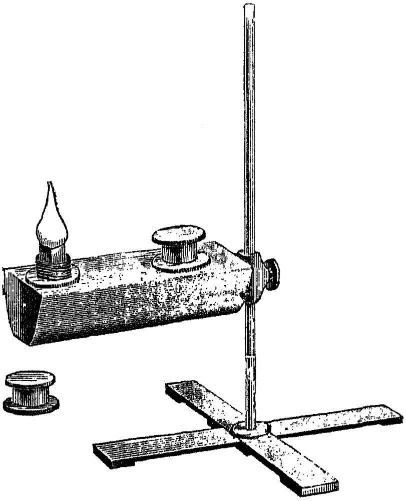
Fig. 6.

When more convenient material is not at hand, candles of good quality will answer for most purposes. A large candle with a flat wick can be easily made, and is some improvement on the ordinary form. For heating glass tubes, boiling liquids in test-tubes, etc., it is desirable to have a flame which does not deposit soot, and if

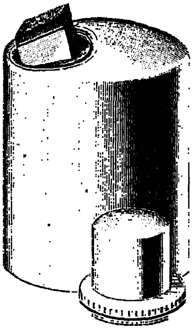

Fig. 7.

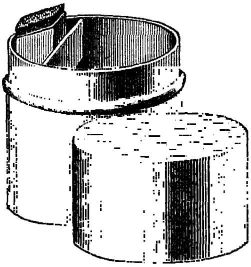

Fig. 8.

a Bunsen burner cannot be used, an alcohol lamp, Fig. 9, with a circular wick 10 to 15 mm. in diameter, is needed. Such a lamp, however, is not adapted for use with the blowpipe, as the flame is not rich enough in carbon to give suitable reduction effects.

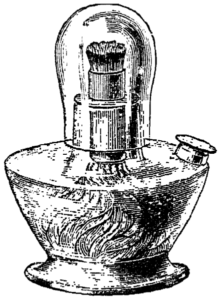

Fig. 9.

Platinum-pointed Forceps.—These are indispensable for holding fragments of minerals which are to be heated before the blowpipe. Fig. 10 represents the usual form. They are made of steel, and should be nickel-plated. The platinum points are opened by pressure, and are rendered self-closing by means of a spring, which should not be too strong. The platinum needs occasional cleaning, which is best done by scouring with sea-sand.

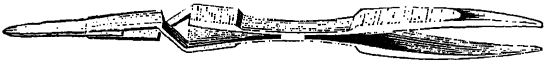

Fig. 10.

The steel ends are useful for picking up and handling fragments of minerals and for detaching pieces from specimens. The only precaution that is needed in the use of the forceps is never to allow minerals with metallic luster to fuse against the red-hot platinum, since the latter may form a fusible alloy with lead, arsenic, antimony, or other readily reducible elements. If the platinum does become alloyed, it is best to cut off the ends of the forceps, and reshape them with a file.

Platinum Wire.—This is used for supporting beads of fused borax, salt of phosphorus, or other fluxes, and for introducing powders into the flame. A kind about 0.4 mm. in diameter (weighing 0.247 grs. for every 10 cm.) is best.

Loops.—For the support of fluxes, loops, Fig. 11, are used, which are made by bending the platinum wire over a conical point. As a rule, these loops should be from 3 to 4 mm. in diameter. The beads may generally be removed by straightening out the wire, or sometimes by dissolving them in acid.

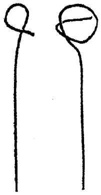
Fig. 11.

The double loop is made by grasping the wire in the steel end of the platinum-pointed forceps, and making a double turn about the latter. It is only recommended to serve as an additional support when a considerable quantity of material is to be fused with some flux.

Holders.—A contrivance like Fig. 12 is convenient for holding platinum wire. Short pieces of wire may also be fused into the end of a glass tube or rod.

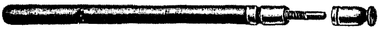
Fig. 12.

Platinum Spoons.—These may be usefully employed in a few operations where fusions are to be made. Preferably the spoon, Fig. 13, should have a bowl 18 to 20 mm. in diameter, and need not weigh over 1.25 grams. It is held in the platinum forceps, and the fusions may be soaked out by digestion in a test-tube with water or acids. Spoons with long handles, Fig. 14, are often recommended, but they are necessarily heavier, and are not very serviceable if the bowls are small.

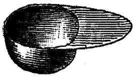
Fig. 13.

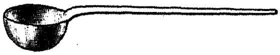
Fig. 14.

Charcoal.—This is used in many operations as a support for the assay, and, moreover, the carbon often assists in bringing about reductions. For most purposes, any piece of well-burned charcoal that does not snap nor become fissured in the flame will suffice. The kinds made from basswood, pine, or willow are recommended. It is a good plan to have the material sawed out into rectangular blocks of about 10 × 3 × 2 cm. Excellent charcoal, prepared especially for blowpipe work, can be procured from dealers.

Usually the assay is best heated on a smooth, flat surface, although occasionally a slight depression or cavity, which may be cut with a penknife, is needed.

A good piece of charcoal will last for some time, a clean surface being afforded by filing or cutting away the part that has been used.

For the uses of charcoal, see p. 39.

Gypsum Tablets.—These are prepared by making plaster of Paris into a thin paste with water, pouring this upon a sheet of glass, and spreading it out evenly until it is about 3 or 4 mm. thick. Before the plaster sets, its surface is ruled off by means of a knife into rectangular blocks about 4 × 8 cm. across, which are removed after the plaster hardens.

These tablets are admirably adapted for collecting sublimates, especially colored ones, and, as recommended by Haanel,* are used as follows:

The finely powdered material to be tested is placed near one end of the tablet, moistened with a few drops of hydriodic acid, and heated at the tip of a small oxidizing flame. The iodides, as they volatilize, condense on the white gypsum as coatings, some of which are very beautiful. White coatings may be collected on tablets which have been previously blackened by holding them over a sooty flame. As a substitute for hydriodic acid, Wheeler and Luedeking† have found that ordinary tincture of iodine answers in most cases, and an iodide of sulphur, prepared by fusing 4 parts by weight of iodine and 6 of sulphur, is of still more general application. Moses‡ suggests using a flux prepared by mixing 2 parts of sulphur, 1 of potassium iodide, and 1 of potassium bisulphate.

Glass Tubing.—A supply of *hard* glass tubing, varying from 3 to 6 mm. in internal diameter, is needed for making closed and open tubes.

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* Trans. Roy. Soc. Canada, Section III, p. 65, 1883.

† Trans. St. Louis Acad. of Sci., vol. iv, p. 676, 1886.

‡ School of Mines Quarterly, New York, vol. x, p. 320, 1889.

Closed Tubes.—These are tubes closed at one end, Fig. 15, and should be about 8 cm. long, and 3 to 4 mm. in internal diameter. They may readily be made by heating a tube of twice the required length, at the middle, in a Bunsen-burner flame, and turning it slowly so that the glass will be uniformly heated. When the glass becomes quite soft, the tube is removed from the flame and pulled in two. The slender terminations are then removed by holding the end of the tube nearly through the flame, allowing the glass, where it has been pulled out and is quite thin, to fuse together, and then pulling away the termination.

Fig. 15.

These tubes are used for heating substances out of contact with, or with but limited access of, air. Substances are best introduced in the form of fragments, which drop to the bottom of the tube, leaving the walls perfectly clean.

The principal effects that may be observed, when substances are heated in closed tubes, are the distillation or giving off of volatile products (gases, liquids, or solids), which collect in the upper, cold part of the tube; but any change which the material undergoes should be carefully noted.

For a list of the closed-tube reactions, see Chapter IV, p. 139.

Bulb Tubes.—Tubes with a bulb at one end, Fig. 16, are employed in a number of operations. They may be made by heating the end of a tube like that shown in Fig. 15 over a blast-lamp until the glass becomes quite soft, and then blowing a bulb of the desired size. With a Bunsen-burner or alcohol flame, sufficient heat cannot be obtained to make these tubes from hard glass, but if one is not able to blow them, they can be procured from dealers. A good size for the bulb is from 12 to 18 mm. in diameter.

Fig. 16.

Open Tubes.—These are tubes, open at both ends, which are employed in heating or roasting substances in a current of air, and thus bringing about oxidation. The tubes should be from 5 to 7 mm. in internal diameter and 15 to 17 cm. long. The substance (best in the form of fine powder, so as to expose a maximum surface to the air) is placed about 4 cm. from one end. This may be readily accomplished by putting the powder upon a slip of paper, folded into a V-shaped trough, slipping this to the desired distance into the tube, and inverting. The tube, held in a slanting position (from 20° to 30°), with the powder in the lower end, is then heated for some time, first just above the substance to insure a draft of air, and finally directly under it. Straight tubes can be used for almost all experiments, but sometimes the powder has a tendency to fall out, and then a bent tube, Fig. 17, may be used. The powder is placed near the bend, and the flame applied somewhat above it so as to insure a draft of air.

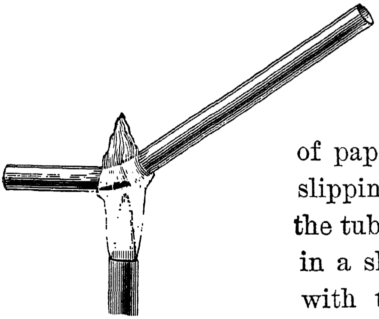

FIG. 17.

For a list of the open-tube reactions, see Chapter IV, p. 141.

Diamond Mortar.—The most convenient form is shown in Fig. 18. It is made from the very best tool-steel, and is almost indispensable for pulverizing minerals. A small fragment, not over 5 mm. in diameter, is placed in the cavity; the pestle is then

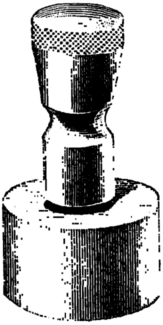

FIG. 18.

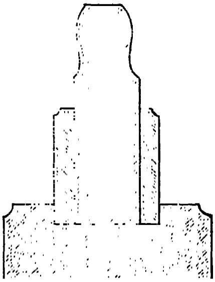

FIG. 19.

inserted, and struck several sharp blows with a hammer. If the pestle, which should not fit too closely, is twisted so as to give a sort of milling motion, a very fine powder can be obtained. The mortar can be readily cleaned by grinding up bits of glass and wiping the cavity and pestle with a dry cloth.

Mortars made in three parts, Fig. 19, which are frequently recommended and kept in stock by dealers, are not as serviceable as the kind described in the foregoing paragraph.

Agate Mortar and Pestle.—These, Fig. 20, are used for reducing minerals to a very fine powder. The mortar should be from 5 to 8 cm. in diameter. The mortar and pestle are used for grinding, *never* for pounding hard bodies.

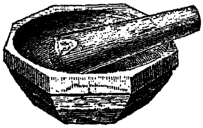

Fig. 20.

If a diamond or agate mortar is not at hand, mineral fragments may be pulverized by wrapping in several folds of thick paper, and hammering on an anvil. A cheap porcelain mortar will also serve for grinding all but very hard minerals.

Hammer.—A small, artisan's hammer will answer most purposes.

Anvil.—A small block of hardened steel, or any convenient flat steel surface (as the base of a diamond mortar) is suitable.

Pliers.—Cutting-pliers are very serviceable for detaching and breaking up small fragments of minerals. Those shaped like Fig. 21 are made especially for this purpose, but ordinary pliers, such as are used for cutting wire, are an excellent substitute.

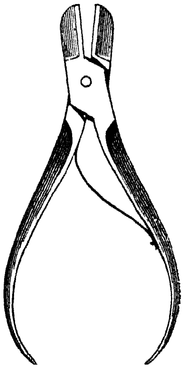

Fig. 21.

File.—A small three-cornered file is used for cutting glass tubes. A notch is cut in one side of the tube, which is then half pulled, half broken in two.

Magnet.—A common horseshoe magnet, or a magnetized knife-blade, serves to recognize magnetic bodies. A magnetic needle is sometimes useful for delicate determinations.

Lens.—A good magnifying-glass will be found very useful.

An achromatic triplet, of about 1 inch focal length, is best, but is expensive, and a cheaper form of lens will answer.

Watch-glasses.—A number of these, from 3 to 4 cm. in diameter, will be found convenient for holding mineral fragments and powders. Small butter-plates or white porcelain India-ink slabs with three or more depressions serve the same purpose.

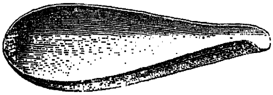

FIG. 22.

Metal Scoop.—This, Fig. 22, is well adapted for handling powders, and especially for transferring them to tubes.

Ivory Spoon and Spatula.—An ivory spoon, Fig. 23, with a bowl 5 × 10 mm. inner diameter, is useful for handling powders and dry reagents. The handle, if thin and flat, serves as a spatula for handling and mixing reagents. A knife-blade also makes an excellent spatula.

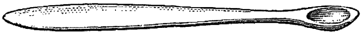

FIG. 23.

Test-tubes.—For making tests in the wet way, test-tubes are very necessary. They should be from 15 to 20 mm. in diameter and about 16 cm. long. A large feather will be found very convenient for cleaning such tubes. A test-tube stand, Fig. 24, and some form of holder, for use when liquids are to be boiled, should be obtained. One like Fig. 25 can be cut from a piece of pine.

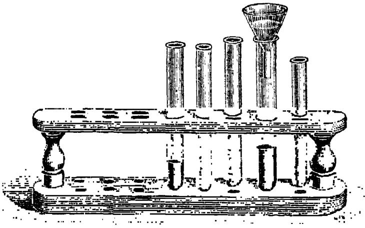

FIG. 24.

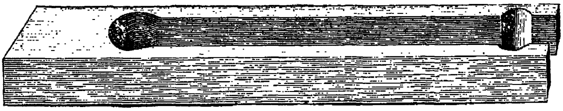

FIG. 25.

Beakers and Flasks.—A few of these, of various sizes, will prove of much service. The largest ones need not have a capacity of over 150 cc.

Funnel and Filter-paper.—A glass funnel about 5 cm. in diameter and a supply of filter-papers are needed. It will be well to buy cut papers, 7 and 9 cm. in diameter, from dealers.

Filtering and Washing.—To make a filtration, a piece of paper is folded twice upon itself, thus forming a quadrant, and this is opened so as to form a conical cup, having three thicknesses of paper on one side and one on the other. It is snugly inserted into a dry funnel, and moistened with water. The material to be filtered is then poured upon the paper, care being taken not to have it go above the top. When the liquid has all run out, water is added till even with the top of the paper, or dropped around the edge so as to moisten every part. By repeating this several times, the soluble materials are wholly *washed* away from the insoluble portions.

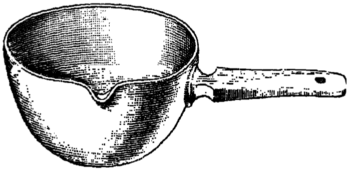

FIG. 26.

Porcelain Dishes.—Those with handles, called *casseroles*, Fig. 26, are most convenient for boiling liquids and making evaporations. From 7 to 9 cm. in diameter is a good size.

Porcelain Crucibles.—These should be about 3 cm. in diameter, and are useful in a number of ways, especially for obtaining a small quantity of a precipitate which has been collected upon a filter-paper and needs to be subsequently examined. For this purpose the paper is put into the crucible, and the latter, supported on a triangle made of iron wire, Fig. 27, is heated over a

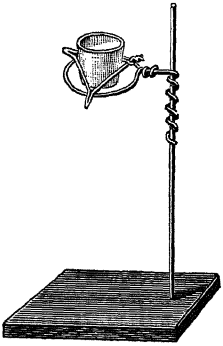

FIG. 27.

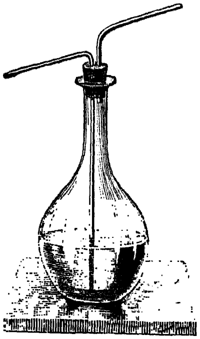

FIG. 28.

lamp until the carbon of the paper has completely burned away, leaving the precipitate together with the trifling ash of the paper.

Lamp-stand.—This may be purchased from dealers, or one like Fig. 27 may be easily made. By slightly bending the coil of wire which goes about the upright, the proper degree of tension may be obtained, so that the ring will move readily up and down, and yet stay fixed in any position.

Wash-bottle.—This, Fig. 28, can be made from a flask, or from any bottle having a neck wide enough to receive a doubly perforated stopper.

Dropping-bottles and bulbs.—A form like that shown in Fig. 29, about 35 mm. in diameter, is convenient for water, when only a small quantity is needed. If less than two thirds full, by closing the larger opening and inverting, the heat of the hand will expand the air and drive out the water drop by drop. Fig. 30 represents a form with a bulb 30 mm. in diameter, and is convenient for holding reagents which are to be used a drop at a time. In order to fill it, the bulb is warmed and the end dipped under the surface of the liquid, when, on cooling, a few drops of the latter will enter. This is then boiled to expel the air, and the tip again brought quickly under the liquid, when the condensation of the steam will cause the liquid almost immediately to rush in. The bulb should not be more than two thirds full. A convenient form of dropping-bottle with hollow stopper is shown in Fig. 31.

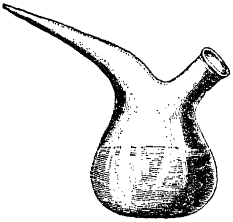

FIG. 29.

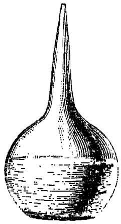

FIG. 30.

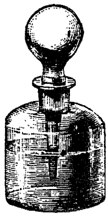

FIG. 31.

Pipette.—A glass tube of 5 mm. inner diameter, heated over a lamp and drawn out to a capillary, Fig. 32, will serve as a *pipette*, and will be found useful for taking up small quantities of liquids and introducing them into tubes.

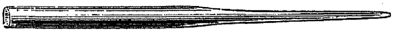

FIG. 32.

PART 2. REAGENTS.

Reagents are substances employed to produce changes in bodies, in order to test their composition. They are known as *dry*, *gaseous*, or *wet*, according as they are used in the solid, gaseous, or liquid form. Most of them can be obtained, sufficiently pure, at drug stores or from dealers in chemicals. The solids and liquids should be carefully labelled and kept in suitable, well-stoppered bottles. For greater convenience, however, it is well to have on hand a supply of some of the more common dry reagents in wooden or glass pill-boxes about 4 cm. in diameter.

DRY REAGENTS.

Sodium Carbonate, Na_2CO_3.—Dry sodium carbonate may be purchased, or it may be made by heating the commercial bicarbonate in a porcelain dish until it becomes anhydrous. Sodium carbonate is used for decomposing many substances, and owes its action to the tendency of sodium to unite with non-metallic or acid-forming elements. Thus, $ZnS + Na_2CO_3 = Na_2S + ZnO + CO_2$. Fusions with sodium carbonate are frequently made in a loop on platinum wire, and in order to obtain a bead, it is recommended to make the material into a thick paste with water, to take this up in the loop, Fig. 11, and to fuse in an oxidizing flame. The bead should be clear when hot, but white and opaque when cold. If heated in the reducing flame, it will be brown, owing to the presence of carbon.

For a list of some of the reactions with sodium carbonate, see Chapter IV, pp. 145 and 151.

Borax, or Sodium Tetraborate, $Na_2B_4O_7.10H_2O$.—The crystallized commercial salt is usually sufficiently pure, and is broken into coarse powder for use. Borax is generally fused into a bead on platinum wire, and to make this, the platinum loop, Fig. 11, is heated and touched to the salt, and the adhering material fused before the blowpipe until a clear glass is obtained. The bead should be lenticular in shape, and clear and colorless. To introduce the material to be tested into the bead, touch the latter when hot to a small particle of the substance, or to a little of the powder, and heat before the blowpipe. Borax dissolves various substances, especially the oxides of the metals, and with many of them gives characteristic colors.

For a list of the tests, see Chapter IV, p. 148.

Borax-glass.—This is needed for only a few experiments. A little at a time may be made by fusing borax in a rather large loop on platinum wire, and crushing the glass in a diamond mortar. It may also be purchased.

Phosphorous Salt, or Hydrogen Sodium Ammonium Phosphate, $HNaNH_4PO_4.4H_2O$; sometimes called *Microcosmic Salt.*—This is generally fused into a bead on platinum wire. The bead is made in the same way as the borax one, but the material becomes very liquid, and is apt to drop from the loop when first heated. This may be avoided, however, by heating gently at first, and holding the bead just above the flame, so that the escaping steam and the force of the blast may buoy up the liquid. The salt is changed by fusion to SODIUM METAPHOSPHATE, $NaPO_3$. The reactions with sodium metaphosphate beads are mostly similar to those with borax, and a tabulated list of them will be found in Chapter IV, p. 149.

Test-papers.—*Blue litmus-* and *yellow turmeric-paper* may be purchased from the dealers. The former is turned red by acids, and the latter reddish-brown by alkalies. The turmeric-paper also serves for the recognition of boracic acid and zirconium. For use, these papers are conveniently cut into narrow strips.

Potassium Bisulphate, $HKSO_4$, **and Potassium Pyrosulphate,** $K_2S_2O_7$; sometimes called *Acid Sulphate of Potash.*—This can be made by heating crystallized potassium sulphate with half its weight of concentrated sulphuric acid (10 grams K_2SO_4 and 3 cc. H_2SO_4) in a porcelain dish until vigorous frothing ceases. The fusion solidifies to an opaque mass, which should be pulverized and preserved in a well-stoppered bottle. Heating changes $HKSO_4$ into pyrosulphate, $K_2S_2O_7$, and finally to normal sulphate,

K_2SO_4. A variety of minerals are decomposed by fusion with potassium bisulphate, and such fusions may be made either in the platinum spoon, porcelain crucible, or often even in a test-tube.

Potassium Bisulphate and Fluorite.—The finely pulverized materials, mixed in the proportion of 3 parts of the former to 1 of the latter, are useful for detecting boron in some of its combinations, and it is well to have a small supply of the mixture on hand. The mixture when heated liberates hydrofluoric acid. $2HKSO_4 + CaF_2 = K_2SO_4 + CaSO_4 + 2HF$.

Potassium Iodide and Sulphur.—The pulverized materials, mixed in equal proportions, are used for detecting bismuth and lead.

Oxide of Copper, CuO.—This is useful for detecting chlorine. A little of the oxide may be purchased, or made by dissolving copper in nitric acid, evaporating the solution to dryness, and igniting to redness in a porcelain dish. A little powdered cuprite or malachite will answer equally well.

Potassium Nitrate, KNO_3.—This is used occasionally for fusing with minerals when an oxidation is required.

Bone-ash.—This is needed for the silver assay. It will be best to purchase a small supply from a dealer.

Granulated Tin, Zinc, and Lead.—These may be purchased from the dealers. The first two are used, generally with acids, in making *reductions*, as they dissolve in acids with evolution of hydrogen, and change many combinations from a higher to a lower valence. Thus, $2FeCl_3 + Zn = 2FeCl_2 + ZnCl_2$, or possibly $FeCl_3 + H = FeCl_2 + HCl$. Lead is used for the silver assay, and should be free from silver. This is commonly called *test-lead.*

Magnesium.—This may be useful for detecting phosphoric acid. It is best to have the magnesium ribbon.

GASEOUS REAGENTS.

Hydrogen Sulphide, H_2S.—When a little of this reagent is needed it may be generated in the simple apparatus shown in Fig. 33. The bottle contains fragments of ferrous sulphide, FeS, and concentrated hydrochloric acid diluted with an equal volume of water is poured in through the thistle-tube, so as to give as nearly constant a flow of gas as possible. $FeS + 2HCl = H_2S + FeCl_2$. By means of a glass tube and a rubber connection, the gas may be led into any liquid in order to bring about a precipitation.

Chlorine, Cl.—This reagent is seldom needed, but a little of it may be prepared by warming powdered pyrolusite, MnO_2, with concentrated hydrochloric acid (p. 101), and carrying off the chlorine by means of a bent glass tube running through a perforated cork. *Chlorine-water*, or water saturated with chlorine gas, is sometimes used.

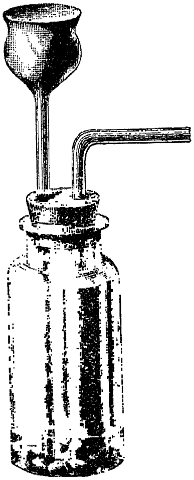

FIG. 33.

WET REAGENTS.

Wet reagents, especially *acids*, should be kept in bottles with ground-glass stoppers, and should be handled carefully. Acids when boiled give off disagreeable and corrosive fumes, and it is quite essential that these should be carried off by a good draft, which may be accomplished by arranging a *hood* or small chamber connecting with a chimney-flue. If acids are spilled upon fabrics, the spots should be immediately moistened with ammonia to neutralize the acid, and then thoroughly washed with water.

Water.—Distilled water is best, but clean rain-water may be substituted. It is convenient to keep a supply of water in a wash-bottle, Fig. 28.

Hydrochloric Acid, HCl.—This reagent is a solution of HCl gas in water. The pure concentrated acid of the dealers contains about 40% HCl, and for most operations it is best to use the acid diluted with an equal volume of water.

Nitric Acid, HNO_3.—This is useful for dissolving many minerals, and in the concentrated form it is a *strong oxidizing agent.* The acid is exceedingly corrosive and needs to be handled very carefully.

Nitrohydrochloric Acid, or Aqua Regia.—This is prepared by mixing 1 part of nitric acid and 3 of hydrochloric. It is a powerful solvent and oxidizing agent.

Sulphuric Acid, H_2SO_4, **or Oil of Vitriol.**—This needs to be handled with much care. When added to water, a great deal of heat is generated, and when hot (boiling-point 338° C.), water *should never* be added to it. For many tests it is well to employ a dilute acid, made by adding 1 volume of acid to 4 of water.

Hydriodic Acid, HI.—This is needed for only a few tests, and does not keep well, as it decomposes, with separation of free iodine. It may be prepared by suspending iodine in water, passing hydrogen sulphide gas into the liquid until the solution becomes colorless, and then decanting from the separated sulphur. It is convenient to keep a supply of this in a dropping-bottle, Fig. 31.

Hydrochlorplatinic Acid, H_2PtCl_6; often called *Platinic Chloride.*—This is useful for detecting potassium in presence of lithium and sodium. Its preparation is explained under platinum (Chapter III, p. 103).

Ammonium Hydroxide, NH_4OH; commonly called *Ammonia.*—This reagent is a solution of ammonia-gas, NH_3, in water. It is a strong *alkali*, and should not be added to acids unless the latter are cold and dilute.

Potassium Hydroxide, KOH.—This is another strong *alkali.* Its solution does not keep well in glass, and it will be found more convenient to have the *stick potash* broken up and preserved in a well-stoppered bottle.

Barium Hydroxide, BaO_2H_2.—A solution of this may be prepared by dissolving the crystallized salt in 20 parts of warm water, cooling and filtering off the insoluble material, which consists mostly of barium carbonate. *Calcium hydroxide, lime-water,* CaO_2H_2, may be substituted, and is prepared by shaking up a small quantity of quicklime with water, allowing this to stand for some hours, and then decanting off the clear liquid.

Ammonium Sulphide, $(NH_4)_2S$.—This may be prepared by saturating a little ammonia with hydrogen sulphide, and then adding two thirds the volume of the same ammonia. On long standing it turns yellow, and then contains an excess of sulphur.

Ammonium Molybdate, $(NH_4)_2MoO_4$.—This is almost indispensable for the detection of phosphates. It may be prepared by dissolving *molybdic oxide*, MoO_3, in ammonia, and pouring the solution into dilute nitric acid, being careful to have an excess of the latter. The solution is allowed to stand, and anything that may separate out is filtered off.

Cobalt Nitrate, $Co(NO_3)_2$.—The crystallized salt is dissolved in 10 parts of water, and the solution kept most conveniently in a dropping-bulb, Fig. 30. It is used for moistening infusible substances, especially those containing aluminium and zinc, which are afterwards intensely ignited before the blowpipe, and assume characteristic colors. Cobalt nitrate when ignited is decomposed, yielding a deposit of cobalt oxide upon the assay, ($Co(NO_3)_2 = CoO + 2NO_2 + O$), and this oxide unites with it, giving colored compounds of unknown composition. The reagent may be applied to a fragment of mineral held in the platinum forceps, but the reaction usually succeeds better if the finely powdered mineral is made into a thin paste with the cobalt nitrate solution, and a little of this, placed upon charcoal, is *intensely ignited* before the blowpipe. This latter method is especially recommended for hard and compact minerals.

Aqueous solutions of the following salts may be kept in glass-stoppered bottles, or, if they are to be used only occasionally, it is recommended to keep a supply of the pulverized dry salts on hand, and to dissolve a small quantity in a test-tube when needed.

Ammonium Carbonate, $(NH_4)_2CO_3$.—The commercial, dry salt is a mixture of ammonium bicarbonate, HNH_4CO_3, and ammonium carbamate, $NH_2NH\ CO_2$. Its solution in water, however, may be regarded as containing normal ammonium carbonate, $(NH_4)_2CO_3$.

Ammonium Oxalate, $(NH_4)_2C_2O_4.2H_2O$.

Di-Sodium Hydrogen Phosphate, $Na_2HPO_4.12H_2O$; commonly called *Sodium Phosphate.*

Barium Chloride, $BaCl_2.2H_2O$.

Silver Nitrate, $AgNO_3$.

Potassium Ferrocyanide, $K_4Fe(CN)_6.3H_2O$.

Potassium Ferricyanide, $K_6Fe_2(CN)_{12}$.—An aqueous solution of this salt does not keep well.

Ammonium Sulphocyanate, NH_4CNS.

The list of reagents, both wet and dry, might be considerably enlarged, but the principal ones have been given, and those not in the list which are mentioned in subsequent chapters can be easily procured. Any reagents used in a well-equipped chemical laboratory may at times be found convenient.

Solution.—Of the foregoing reagents, water and the acids are commonly employed for dissolving substances. The appropriate solvent for a mineral can be learned only by experience or by a knowledge of the chemical composition of the material. As most minerals are insoluble in water, its use as a solvent is limited. Hydrochloric acid is most generally employed, and is preferred to other strong acids, as it is safer to handle. Nitric acid is needed when an oxidation is required, as when sulphides or arsenides are to be dissolved. It is seldom necessary to use sulphuric acid.

In order to dissolve a mineral it is best to treat some of the *very finely powdered material* in a test-tube with from 5 to 10 cc. of the solvent (it may be necessary to try several solvents before the appropriate one is found), and, if the material does not dissolve in the cold liquid, the contents of the tube should be heated to boiling, which, in the majority of cases, greatly facilitates solution.

Precipitation.—When insoluble compounds are formed by adding reagents to solutions, the process is called *precipitation.*

When solutions are mixed, precipitation will take place, provided an insoluble compound can be formed by the interchange of the chemical constituents. For example, when aqueous solutions of sodium chloride and silver nitrate are mixed, a white precipitate of silver chloride will be formed, because silver chloride is insoluble in water. $NaCl + AgNO_3 = AgCl + NaNO_3$. Precipitation furnishes a means for detecting many elements, and it is also useful for separating substances, since the insoluble precipitates may be collected on filter-papers and thus removed from solutions.

PART 3. ON THE NATURE AND USES OF FLAMES.

Combustion.—This is ordinarily an *oxidation process*, and where a flame is produced, the latter results from the combination of carbon and hydrogen of different gases and vapors with the oxygen of the air, the final products of the oxidation being carbon dioxide, CO_2, and water, H_2O.

When a lamp or candle is burning, the oil or the melted material of the candle is carried up into the wick by capillary attraction, and is there converted by the heat of the flame into gas or vapor, which burns. Such gases, as well as ordinary illuminating-gas, are not definite chemical compounds, but mixtures, usually of different combinations of carbon and hydrogen, and are known as hydrocarbons. Water-gas, with which many cities are now supplied, is made by blowing steam through glowing coals, when the following reaction takes place: $H_2O + C = 2H + CO$. The resulting gas (a mixture of hydrogen and carbon monoxide), which burns with a non-luminous flame, has to be mixed with some volatile material rich in carbon, in order to make it luminous.

The Candle Flame.—This, Fig. 34, has been chosen as representing a typical luminous flame, and may be regarded as containing three distinct parts, as follows:

(1) An outer part, *a*, where the gases are fully exposed to the oxygen of the air, and where the combustion is com-

plete; that is, where carbon is burned to CO_2, and hydrogen to H_2O. These gases form an invisible envelope about all ordinary flames.

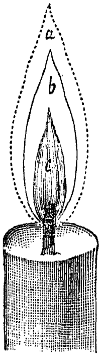

Fig. 34.

(2) An inner zone, *b*, the *luminous part of the flame*, is characterized by an incomplete combustion, since only a limited supply of oxygen, which penetrates the outer envelope, is available. Hence, carbon burns to its lower oxide, carbon monoxide, CO, while hydrogen forms H_2O. Moreover, the heat of the flame decomposes some of the gas, with separation of *finely divided carbon.* This being heated to incandescence renders the flame luminous, and will deposit as soot upon any cold substance held in the flame.

(3) Still further within the flame is the zone *c*, which contains the unburned gases as they are first formed by the heat and rise up from the wick.

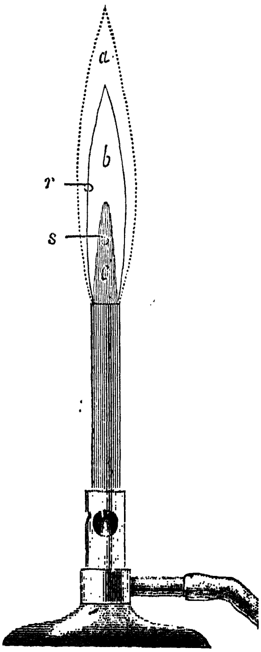

Fig. 35.

The three zones, *a*, *b*, and *c*, naturally grade into one another, and are not separated by sharply defined boundaries.

The Bunsen-burner Flame.—This, Fig. 35, has three zones corresponding to *a, b*, and *c*, of the candle flame, except that sufficient air is allowed to mix with the gas to prevent the separation of carbon in *b*. The flame, therefore, is non-luminous and deposits no soot. The outer envelope, *a*, containing CO_2 and H_2O, is invisible; the zone *b*, containing CO, some CO_2, and H_2O, is pale violet; and the inner zone, *c*, containing a mixture of unburned gas and air, is sharply outlined against *b* by a pale blue border.

Special precautions should be taken that the flame does not *snap down* and burn at the base.

The Blowpipe Flame.—This is produced by placing the tip of the blowpipe into the gas or lamp flame, and blowing a moderately strong blast of air. If a gas flame is used, it should burn from the jet *e*, Fig. 4, p. 13, and should be from 3 to 4 cm. high.

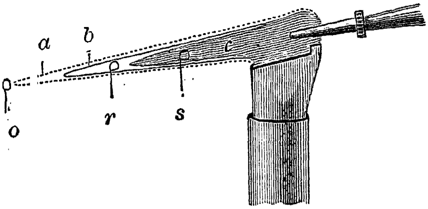

Fig. 36.

The operator should be comfortably seated at the table, his arm resting upon its edge, and the blowpipe grasped near the water-chamber, between the thumb and first and second fingers of the right hand. The blast should be so regulated that the flame will be deflected into a slightly tapering, distinctly outlined, blue cone, Fig. 36, in which the zones *a*, *b*, and *c*, correspond exactly to those of the Bunsen-burner flame. The flame should not appear luminous, except, perhaps, a small portion just above the blowpipe tip, which is not carried along by the draft. If the hole in the tip is well bored, the flame will neither flutter nor show irregularities, even when the blast is strongest.

Heating and Fusion.—The hottest part of the blowpipe flame is at *r*, Fig. 36, just beyond the tip of the inner blue cone. At this point, minerals are heated to determine their fusibility or other phenomena which they may exhibit. Even platinum can be readily melted if in the form of fine wire (not over 0.2 mm. in diameter), so as not to radiate nor conduct away the heat too rapidly.

In testing minerals, the size and shape of the fragment to be used is a matter of considerable importance. If too large, it is difficult, often impossible, to heat it up to the desired temperature, while, if too small, the reaction may not show with sufficient distinctness. Beginners almost invariably err in taking too large pieces. Usually the reaction succeeds best either with a splinter or a fragment with a thin edge, and a size about as large as a lead-pencil point (1 mm. in diameter and 4 mm. long) can be recommended. The fragment should be held in the forceps in such a manner that the greater part of it projects free beyond the platinum tips in order that heat may not be wasted in warming up the metal, and so that a point or thin edge of the mineral is turned in the direction of the flame, Fig. 37. Any change which the mineral undergoes may be a help in its identification, and should be carefully noted; e.g., whether fusible or infusible, and in the former case the degree of fusibility and the manner in which the mineral fuses, whether quietly or with intumescence (swelling); whether to a clear, white, or vesicular (full of bubbles) glass; whether to a light- or dark-colored mass or slag, or to a magnetic or non-magnetic mass.

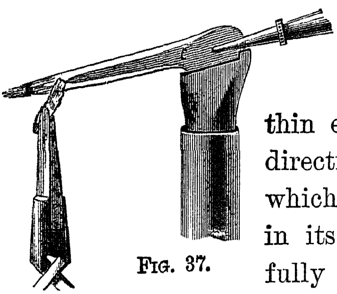

FIG. 37.

Decrepitation.—It frequently happens that a mineral, when introduced into the blowpipe flame, snaps or explodes, so that it is difficult and often impossible to secure a piece which can be held in the forceps and heated. This phenomenon, known as *decrepitation*, may be due to unequal expansion of the material. More often, however, it results from the presence in the mineral of minute cavities containing gases or liquids (commonly water, sometimes liquid carbon dioxide), the expansion of which causes the explosion.

At times a fragment of a decrepitating mineral may be heated in the forceps, if at first very carefully introduced into the ordinary gas or lamp flame, so that it becomes slowly and uniformly heated before being subjected to the more intense heat of the blowpipe flame. Another way is to heat several large pieces in a closed tube until decrepitation ceases, when, on dumping out the fragments, one may be selected of the right size and shape to be taken in the forceps and heated before the blowpipe. When the above methods fail, the following, suggested by Berzelius, may be resorted to: Grind the mineral to a very fine powder, make into a thin paste with water, then spread out a drop of this upon a clean charcoal surface, and heat before the blowpipe, at first very gently, finally as intensely as possible. If fusion has not already been observed, a coherent cake will usually be obtained, which with care can be lifted in the forceps, and its edge introduced into the blowpipe flame.

Flame Coloration.—The heat of the blowpipe flame is so intense that many substances are volatilized, and several of the elements in them may then be recognized by the colors they impart to the flame (compare table, Chapter IV, p. 136). The test may be made with a fragment held in the *clean* platinum forceps, as shown in Fig. 37, but usually it succeeds better when a minute quantity of the finely powdered material is taken upon a *clean* platinum wire and introduced into the Bunsen-burner or blowpipe flame. For the latter purpose, a wire may be cleaned by heating until it imparts no coloration to the flame, or, if there is much material adhering to it, it may be boiled in any strong acid, then washed with water and heated (compare Sodium, p.115, §1,*b*). The straight wire is next moistened with pure water, and its end touched to the powdered mineral so as to take up a *minute quantity* of the material, which is then introduced into the flame. Often the merest trace that will adhere to a dry wire is sufficient to give a magnificent flame color. The tests are, as a rule, exceedingly delicate, and the essential condition to be fulfilled is that the material shall be heated *hot enough* to volatilize the element or compound which gives the color. Often a sufficient temperature *cannot* be obtained when a rather large fragment held in the forceps, or considerable material supported in a loop on platinum wire, is heated before the blowpipe.

The colors are best seen in a dark room, but as this is usually not convenient a dark screen (book-cover) as a background will be found advantageous.

Oxidation.—By *oxidation* is meant the union of a substance with oxygen (compare Combustion, p. 31). Many substances when heated before the blowpipe readily take on oxygen from the air and are oxidized. The flame then imparts nothing to them, but simply brings about conditions favorable for the taking up of oxygen. For example, pieces of wood or a copper wire under ordinary conditions may be kept almost indefinitely, but if they are intensely heated, with access of air, the former burns, or *oxidizes*, and the latter is gradually converted into copper oxide, CuO.

Oxidizing Flame.—The flame represented in Fig. 36 is usually called the *oxidizing flame*, and the part favorable for *oxidation* is at *o*, beyond the blue and violet cones, *c* and *b*, and especially where the air *can* and the carbon monoxide in *b* *cannot* have access to the substance.

Reduction.—Usually by the term *reduction* is meant the taking away of oxygen. In a more general sense, it may refer to the formation of a metal from any of its compounds, or to the change of some element in chemical combination from a higher to a lower valence. Thus, the conversion of CuO or Cu_2S to metallic copper, or of $FeCl_3$ to $FeCl_2$ (ferric to ferrous chloride), would be spoken of as reductions.

Reducing Flame.—By means of the blowpipe flame, reductions are made by taking away oxygen, and this is accomplished by heating substances so that they are exposed to the action of *carbon monoxide.* Carbon monoxide, CO, is a *reducing gas*, since it has a tendency to take on oxygen and become carbon dioxide, CO_2. Many oxides, therefore, when heated with CO give up their oxygen, and are *reduced* either to a metal or to a lower oxide. The following equations will illustrate this: $CuO + CO = Cu + CO_2$, and $Fe_2O_3 + CO = 2FeO + CO_2$. The part of the flame most favorable for reduction is at *r*, Fig. 36, where the heat is intense and carbon monoxide predominates. When a substance is large, it is frequently impossible to make a satisfactory reduction in a flame like that shown in Fig. 36, for, while a portion is exposed to the action of carbon monoxide in the zone *b*, another portion must

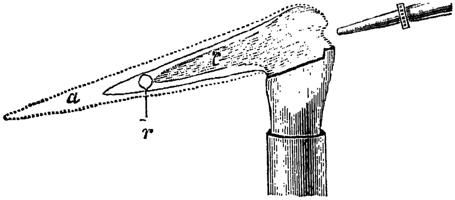

FIG. 38.

project into the air and will there have a tendency to *oxidize.* In such cases, a broader flame, Fig. 38, should be used. This is made by deflecting the gas or lamp flame by a gentle blast, and regulating the latter so that the flame is slightly luminous, but still does not deposit soot upon the assay held at *r*.

Reductions are frequently made on charcoal, and the reducing action of the carbon monoxide is then augmented by that of the glowing carbon.

The following experiments will serve to illustrate the use and application of the blowpipe:

a. To prove that water, H_2O, and carbon dioxide, CO_2, are products of combustion, take a dry bottle and for a few seconds deflect a small blowpipe flame down into it, Fig. 39. The water which condenses on the sides of the glass has resulted from the oxidation of the hydrogen in the gas. That the bottle also contains CO_2 may be proved by adding a little clear barium hydroxide water, inserting the stopper, and shaking, when a white precipitate forms, which is barium carbonate, $BaCO_3$. $CO_2+BaO_2H_2=BaCO_3+H_2O$.

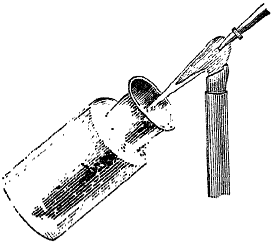

FIG. 39.

b. To show the intense heat of the blowpipe flame, and to acquire skill in the manipulation of the instrument and in maintaining a continuous blast, fuse platinum wire and fragments of minerals used in the scale of fusibility (p. 230). The platinum wire should not be over 0.2 mm. in diameter, and it is best to bend it near the end and hold it end on toward the flame (compare Fig. 37).

c. To show that the inner portion of a flame contains a zone of unburned gas, make use of a Bunsen-burner flame, Fig. 35, and hold a glass tube across it at *r* until it becomes quite soft; then remove from the flame, and draw out to a narrow tube. Next, hold the narrow tube across the flame at *s*, and observe that it softens in two places where it passes through the edges of the flame, but the portion within the cone *c* neither fuses nor becomes red-hot. By holding one end of a rather narrow glass tube in *c*, a little of the unburned gas may be drawn off to one side, and burned at the other end of the tube.

d. To make a flame test, take a fragment of barite, $BaSO_4$, in the forceps, and heat before the blowpipe, as shown in Fig. 37, until a distinct color is obtained. Barium imparts a yellowish-green coloration to the outer part of the flame. Barite also fuses at about 3 in the scale of fusibility, and is very apt to decrepitate. Also test the flame coloration by taking up powdered barite on platinum wire, as directed on p. 35, and heating both in the blowpipe and the Bunsen-burner flames. In the latter case, introduce the material into the edge of the flame, at about *r*, Fig. 35.

e. To test the reducing character of the blowpipe flame, make some experiments with hematite, Fe_2O_3 (a splintery variety is best), which should not be magnetic before heating, but becomes so upon reduction to a lower oxide, FeO. Taking a fresh fragment for each experiment, hold it in the forceps, and heat before the blowpipe for several seconds at the points *o*, *r*, and *s*, Fig. 36, and, after cooling, test with a magnet. If the fragments become at all magnetic, it shows that the reducing gas, carbon monoxide, was present in that part of the flame where they were heated. $Fe_2O_3 + CO = 2FeO + CO_2$. The reduction is strongest at *r*, the tip of the blue cone, where the heat is most intense, and diminishes toward *o*, but it is impossible to make a general statement of just where reduction ceases, as this depends both upon the size of the flame and strength of the blast.

f. To illustrate reduction and oxidation, select a small splinter of hematite, make sure that it is not magnetic, and then heat for an *instant only* in the reducing flame, so as to form FeO sufficient to make the fragment only slightly magnetic. It should then be heated for a considerable time at a point *o*, Fig. 36 (beyond the point where carbon monoxide exists), until the FeO has taken up oxygen from the air, and become oxidized to Fe_2O_3, when the fragment will cease to be magnetic. Considerable care and skill are necessary for performing this experiment successfully. If the fragment becomes very magnetic, it will be best to start with a fresh one, for the oxidation goes on slowly, and it will require a long time for its completion. Further, if FeO has been *fused* on the splinter, it will be almost impossible to complete the oxidation with the blowpipe, since, although the outer surface may be converted into Fe_2O_3, the air will not be able to reach the interior and make the oxidation complete.

g. To further illustrate oxidation and reduction, make a borax bead on platinum wire, as directed on p. 24; touch the bead when hot to a *very small* particle of pyrolusite, MnO_2, and dissolve the latter in the borax by heating at about the point *o*, Fig. 36. If the experiment is successful, the bead should have a fine reddish-violet color, while if it is black or very dark, too much pyrolusite was added, and a new bead should be made. The color is due to an oxide of manganese higher than MnO, and if the bead is heated in the reducing flame, MnO will be formed, and the bead will become colorless. In order to make a reduction of this kind, the following suggestion is offered: Heat the bead very hot at *r*, Fig. 36, where reduction goes on, and then, without interruption, change the position of the blowpipe and the character of the blast in order to make a more bulky flame, Fig. 38, so that the bead may be completely protected from the oxidizing action of the air. If the colorless bead is further heated, so that the air has access to it, the reddish-violet color, characteristic for manganese, will again appear (compare p. 93, § 2). In making both oxidations and reductions, it is a great advantage to be able to heat the substances very hot.

The Uses of Charcoal.—Both reductions and oxidations are made on charcoal. For the former, the best results are obtained by inclining the charcoal, and directing the flame downward, so as to strike the assay a little beyond the tip of the blue cone, as shown in Fig. 40. The combined effect of the flame and the burning charcoal gives an intense heat, and the reducing action may be made very strong. Further, many elements are volatilized, and, passing into the air, take on oxygen and deposit characteristic coatings of oxide on the coal.

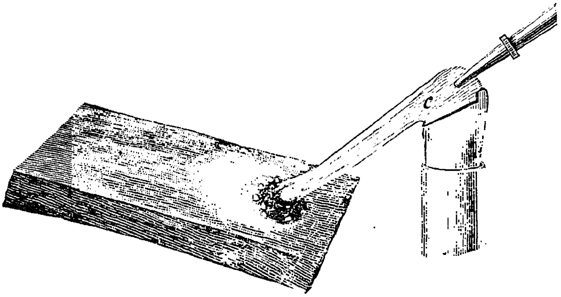

FIG. 40.

For a list of the coatings and the effects of heating on charcoal, see Chapter IV, p. 143.

Roasting.—This is a term which is often applied to the heating of substances in contact with air. It generally results in *oxidation*, and is most conveniently done on charcoal. In order to *roast* a substance, the finely powdered material is spread out on the surface of the charcoal so as to allow free access of air, and is then heated with a small oxidizing flame, Fig. 41, at a considerable distance beyond the tip of the blue cone.

The heat required for roasting is very moderate—scarcely a red heat. If possible, the material should not be allowed to fuse, as it then does not expose sufficient surface to the air. When very fusible minerals are to be roasted, it is often best to mix them with about an equal volume of powdered charcoal, which prevents the material from running together, and subsequently burns away. Another way is to fuse and continue to heat the material until the more volatile constituents are driven out, and then to

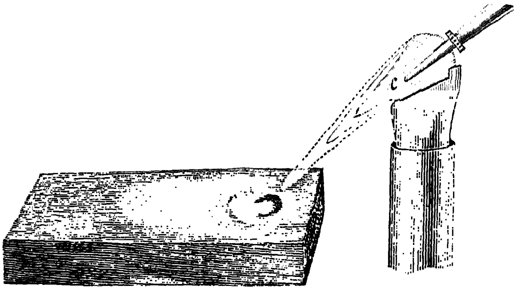

FIG. 41.

pulverize with a little charcoal, and roast carefully by means of a small oxidizing flame.

Roasting is a very important metallurgical process, especially in treating ores containing sulphur, arsenic, or antimony, as these elements are removed as volatile oxides, leaving oxides of the metals which are subsequently reduced.

The following experiments will serve to illustrate some of the effects which may be produced by heating on charcoal:

a. To illustrate the formation of a metal, take a very little powdered malachite $(Cu.OH)_2CO_3$, and three times as much of a mixture of equal parts of sodium carbonate and borax as a flux, moisten to a paste with water, then heat intensely, as shown in Fig. 40, until the copper fuses and collects to a globule.

b. To illustrate the formation of a metal and a coating of oxide, take a little powdered cerussite, $PbCO_3$, an equal volume of powdered charcoal and 3 volumes of sodium carbonate, moisten to a paste with water, then heat for some time, as shown in Fig. 40, until the lead unites to a globule and a considerable coating of yellow lead oxide collects on the charcoal.

c. To illustrate oxidation or roasting, place some finely powdered pyrite, FeS_2, on a flat charcoal surface, spread the material out into a thin layer, and heat very gently with a small oxidizing flame, as shown in Fig. 41. The pyrite is thus oxidized, yielding sulphurous anhydride gas, SO_2, detected by its odor, and a residue of Fe_2O_3, or a mixture of Fe_2O_3 with FeO. If the roasting is continued until the material no longer emits an odor of burning sulphur, the oxidation will be complete, or nearly so, and the residue will have the dark red color of ferric oxide.

CHAPTER III.

REACTIONS OF THE ELEMENTS.

For convenience of reference, the subject matter of this chapter has been arranged alphabetically. In studying the reactions of the common elements, however, it may be recommended to take them up in the following order, which has been chosen partly according to Mendeléeff's *periodic system* of the elements, and partly to bring together some of the elements which exhibit similarities in their analytical reactions:*

1. Hydrogen,	p. *81.*	4. Potassium,	p. *105.*	7. Strontium,	p. *116.*	10. Zinc,	p. *130.*
2. Lithium,	*90.*	5. Magnesium,	*91.*	8. Barium,	*52.*	11. Copper,	*71.*
3. Sodium,	*115.*	6. Calcium,	*58.*	9. Aluminium,	*42.*	12. Silver,	*113.*

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* In the descriptions of tests and experiments, sizes and distances will be given in millimeters and centimeters; quantities of powders and dry reagents in terms of the ivory spoon; and the volume of liquids in cubic centimeters.

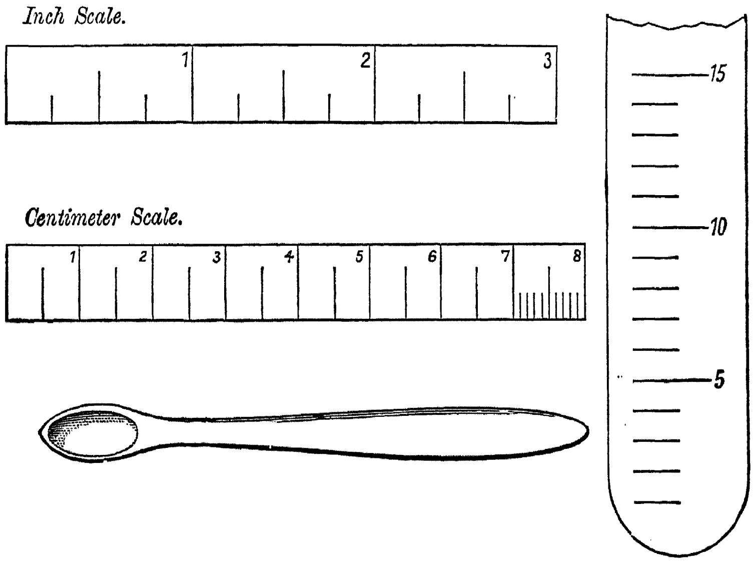


Fig. 42.—Inch and centimeter scales, ivory spoon, and end of a test-tube with cubic centimeters indicated upon it. All natural size.

13. Lead, p. 87.
14. Mercury, 93.
15. Chromium, 69.
16. Manganese, 92.
17. Iron, 83.
18. Cobalt, p. 71.
19. Nickel, 96.
20. Oxygen, 100.
21. Sulphur, 118.
22. Fluorine, 75.
23. Chlorine, p. 67.
24. Boron, 56.
25. Phosphorus, 101.
26. Arsenic, [illegible]
27. Antimony,
28. Bismuth, p. 54.
29. Carbon, 61.
30. Silicon, 107.
31. Titanium, 127.
32. Tin, 125.

Aluminium, Al.—Trivalent. Atomic weight, 27.

Occurrence.—Next to oxygen and silicon, aluminium is probably the most abundant element in the crust of the earth (p. 3). It is a metallic element, occurring most frequently in the group of silicates, while it is also found in a number of oxides, fluorides, phosphates, and sulphates. Kaolinite, $H_4Al_2Si_2O_9$; cyanite, Al_2SiO_5; orthoclase, $KAlSi_3O_8$; almandine garnet, $Fe_3Al_2(SiO_4)_3$; corundum, Al_2O_3; and cryolite, Na_3AlF_6, may serve as examples of its compounds. Aluminium also plays the part of a weak acid, and by some authors, spinel, $MgAl_2O_4 = MgO.Al_2O_3$, and a few similar compounds are regarded as aluminates. Aluminium is a constituent of most rocks, almost the only exceptions being the carbonates, sandstones, and quartzites.

Detection.—Igniting with cobalt nitrate is the only satisfactory blowpipe test for aluminium. For a test in the wet way, precipitation with ammonia is recommended.

1. *Test with Cobalt Nitrate.*—Infusible minerals containing aluminium, if moistened with cobalt nitrate and intensely ignited before the blowpipe, *assume* a fine blue color. Cobalt nitrate on ignition yields cobalt oxide, CoO, which is black, and this oxide unites in some inexplicable way with the alumina to give the characteristic blue color. In applying the test to very hard minerals it is best to powder them, then moisten with cobalt nitrate and heat either on charcoal or on a small loop on platinum wire. The test is restricted to compounds which are light colored, or become so on ignition, and is not characteristic if applied to fusible minerals, as cobalt oxide may impart a blue color to any fused material or flux. Zinc silicates also give a blue color, p. 133.

Apply this test to fragments of cyanite, Al_2SiO_5, held in the forceps, and to finely powdered corundum, Al_2O_3.

2. *Precipitation with Ammonia.*—Ammonia, when added in

slight excess to an acid solution containing aluminium, precipitates gelatinous *aluminium hydroxide*, $Al(OH)_3$. A great many other substances yield, with ammonia, gelatinous precipitates resembling aluminium hydroxide, and therefore it is necessary to make the following additional tests: Collect the precipitate on a filter-paper, wash with water, transfer some of it to a test-tube, and add potassium hydroxide, when the precipitate, if it is aluminium hydroxide, will go easily and completely into solution. Burn the paper containing the precipitate in a porcelain crucible (Fig. 27, p. 22), and test the residue with cobalt nitrate.

Dissolve an ivory spoonful of alum, $KAl(SO_4)_2.12H_2O$, in a test-tube in 5 cc. of hot water, add 2 cc. of hydrochloric acid, and then ammonia in slight excess; that is, until a distinct odor of ammonia is perceptible after the contents of the tube have been thoroughly mixed. Filter off the precipitate, and test as recommended above.

3. *For detecting aluminium in insoluble silicates*, where the above methods cannot be directly applied, see p. 110, § 4.

Ammonium, NH_4.—Univalent. Molecular weight, 18.

OCCURRENCE.—The radical ammonium, NH_4, plays the part of a metal, and in its chemical relations is very similar to potassium. Minerals containing ammonium are of rather rare occurrence, and are generally soluble in water. Sal ammoniac, NH_4Cl, and struvite, $NH_4MgPO_4.6H_2O$, are examples of its compounds.

DETECTION.—Compounds containing ammonium, when boiled with a solution of potassium hydroxide, or heated in a closed tube with lime (ignited calcite), yield the strong and very characteristic odor of ammonia.

Antimony, Sb.—Trivalent and pentavalent. Atomic weight, 120.

OCCURRENCE.—Antimony is found chiefly in combination with sulphur, either as stibnite, Sb_2S_3, or as *sulphantimonites*, which are salts of *sulphantimonious acids*, $H_2Sb_2S_4$, $H_4Sb_2S_5$, $H_6Sb_2S_6$, $H_8Sb_2S_7$, etc. The composition of the sulphantimonites is frequently expressed as a combination of Sb_2S_3 with sulphides of the metals, examples being, — zinkenite, $PbSb_2S_4 = PbS.Sb_2S_3$; jamesonite, $Pb_2Sb_2S_5 = 2PbS.Sb_2S_3$; pyrargyrite, $Ag_3SbS_3 = 3Ag_2S.Sb_2S_3$; and tetrahedrite, $Cu_8Sb_2S_7 = 4Cu_2S.Sb_2S_3$. (See also the sulpharsenites (p. 47), with which the sulphantimonites are frequently isomorphous.) Antimony also occurs native, rarely in combination with metals as *antimonides*, breithauptite, NiSb, and occasionally in different combinations with oxygen, senarmontite, Sb_2O_3, and cervantite, Sb_2O_4.

DETECTION.—Antimony may usually be detected by the coating of oxide formed by roasting on charcoal or in the open tube. The closed-tube reaction is also recommended for sulphide of antimony.

1. *Roasting on Charcoal: Coating of Oxide.*—Most antimony compounds, when heated on charcoal in the oxidizing flame, yield a *dense white sublimate* of oxide of antimony, which deposits quite near the heated part (compare Arsenic), and appears bluish if the coating is thin, so that the black of the charcoal shows through it. The coating is due to volatilization of the antimony and its oxidation in passing into the air. It is quite volatile when heated before the blowpipe either in the oxidizing or reducing flames, and may be driven about and made to change its place on the charcoal. The fumes have no distinctive odor (difference from arsenic). In the absence of other elements which give coatings on charcoal, this test serves as a very simple and characteristic one for the detection of antimony. Where other elements (especially lead and bismuth) interfere, the open-tube reaction will give confirmatory and decisive results.

Some oxides of antimony are not volatile in the oxidizing flame, and when these are to be tested it is necessary to heat them in a reducing flame to convert the antimony to the metallic state, so that it will volatilize and give the coating of oxide described above.

Test the foregoing with stibnite, Sb_2S_3. Place about ¼ ivory spoonful of it on a flat charcoal surface, and heat with a small oxidizing flame (p. 40, Fig. 41) until the material is completely volatilized. Note that the sublimate deposits close to the heated part (difference from arsenic), and test its volatility in both the oxidizing and reducing flames. The odor which may be observed is due, not to the antimony, but to sulphur (p. 119, § 2).

2. *Roasting in the Open Tube: Sublimate of Oxide.*—When metallic antimony and its compounds with sulphur are heated in the open tube, oxides of antimony are formed and deposit as sublimates on the walls of the tube, but the products vary somewhat with the conditions. If sulphur is present, the oxide usually appears as a dense white smoke, and most of it settles for a considerable distance along the under side of the tube, while some of it condenses as a ring rather near the heated part. The ring is Sb_2O_3, and when examined with a lens will frequently be found to consist of two kinds of crystals, octahedrons and prisms, corresponding to senarmontite and valentinite, two forms of Sb_2O_3 found in nature. When heated, this part of the sublimate is completely volatile, and may be driven up and out of the tube, although much more slowly than oxide of arsenic. The white sublimate which condenses along the bottom of the tube is probably antimonate of antimony, $SbSbO_4$. It is *non-volatile*, infusible, and becomes straw-yellow when hot, but white again when cold. In the absence of sulphur and in some compounds containing it (apparently those that oxidize slowly), only the volatile Sb_2O_3 forms. Just why the presence of sulphur causes the formation of the higher oxide is not known, but probably its oxide acts in some way as a means for transferring oxygen, changing Sb_2O_3 to Sb_2O_4.

Test the above with stibnite, Sb_2S_3, using about $\frac{1}{8}$ of an ivory spoonful, and heating very carefully, as directed on p. 19. Test also the volatility of the sublimate, and compare the reaction carefully with the corresponding one for arsenic (p. 48, § 2). To obtain the wholly volatile sublimate of Sb_2O_3, heat a little metallic antimony in the open tube.

3. *Heating in the Closed Tube.*—Sulphide of antimony and many sulphantimonites, when heated in a closed tube, yield a characteristic looking sublimate of oxysulphide of antimony,

Sb_2S_2O. This requires a rather intense heat for its production. It is volatilized with difficulty, and appears black when hot, but changes on cooling to a rich reddish-brown.

Metallic antimony cannot be volatilized in a closed glass tube, except at a very high temperature, where hard glass softens. Owing to this behavior, arsenic and antimony, which frequently occur together, especially in sulpharsenites and sulphantimonites, may sometimes be conveniently separated and identified, since arsenic and its sulphides volatilize readily. After driving the sublimate a short way up the tube, cut off the latter a little below it, and test for the arsenic by the open-tube method (p. 48, § 2). After removing the residue from the tube, test it for antimony, either before the blowpipe on charcoal, or in the open tube. To test for arsenic in presence of antimony, see also p. 49, § 4.

Take a small fragment of stibnite in a closed tube, and heat it at a high temperature and for a considerable time. The small quantity of air in the tube is all that is necessary to bring about the reaction shown by the following equation: $Sb_2S_3 + O = Sb_2S_2O + S$. A slight ring of sulphur deposits beyond the antimony sublimate. This is one of the few closed-tube reactions where the air in the tube plays an important part.

4. *Test with Hydriodic Acid on a Gypsum Tablet.*—Antimony compounds, when treated according to directions given on p. 17, yield a beautiful red coating of iodide of antimony, which disappears when held over strong ammonia.

5. *Flame Test.*—When antimony compounds are heated before the blowpipe in the reducing flame, antimony volatilizes and imparts to the flame a pale greenish color. The precautions against alloying the forceps, mentioned on p. 15, should be observed.

6. *Oxidation with Nitric Acid.*—When antimony or its sulphides are treated with concentrated nitric acid, the antimony is *oxidized* to *metantimonic acid*, SbO_2OH (?), which is a white substance, very insoluble in water and in nitric acid. By diluting with water and filtering, quite a satisfactory separation of antimony may be obtained from other substances with which it is apt to occur in combination. The material on the filter-paper may be

examined for antimony by heating before the blowpipe on charcoal, and the different metals in the filtrate may be precipitated by appropriate reagents. This treatment will frequently be found convenient, especially for detecting a small quantity of antimony in presence of arsenic.

Arsenic, As.—Trivalent and pentavalent. Atomic weight, 75.

Occurrence.—Arsenic usually plays the part of a non-metallic element, and forms three important classes of compounds,—the arsenides, the sulpharsenites, and the arsenates. In *arsenides*, the metals are united directly with arsenic; as nicolite, NiAs, and smaltite, $CoAs_2$. These compounds are analogous to the sulphides and are often isomorphous with them. Several compounds are known which are combinations of arsenide and sulphide; as the commonest of the arsenic minerals, arsenopyrite, $FeAsS = FeAs_2 + FeS_2$. The *sulpharsenites* may be regarded as salts of *sulpharsenious acids*, $H_2As_2S_4$, $H_4As_2S_5$, $H_6As_2S_6$, $H_8As_2S_7$, etc. Examples of these compounds are sartorite, $PbAs_2S_4 = PbS.As_2S_3$; dufrenoysite, $Pb_2As_2S_5 = 2PbS.As_2S_3$; proustite, $Ag_3AsS_3 = 3Ag_2S.As_2S_3$; and tennantite, $Cu_8As_2S_7 = 4Cu_2S.As_2S_3$. The number of Sulphantimonites, is quite large, but they are of rather rare occurrence (compare sulphantimonites, p. 43). Enargite, $Cu_3AsS_4 = 3Cu_2S.As_2S_5$, is a *sulpharsenate* or salt of *sulpharsenic acid*, H_3AsS_4, but other salts of this acid are exceedingly rare. The *arsenates*, salts of *arsenic acid*, H_3AsO_4, are analogous to the phosphates, and although a great many of them are known, they are of rather rare occurrence. Examples are mimetite, $Pb_4(PbCl)(PO_4)_3$; olivenite, $Cu(CuOH)AsO_4$; and scorodite, $FeAsO_4.2H_2O$. In addition to the foregoing classes of compounds, the element occurs as native arsenic, as the sulphides, realgar, AsS, and orpiment, As_2S_3, and sparingly as the oxide, As_2O_3.

Detection.—The method that should be used for the detection of arsenic depends upon whether or not the mineral contains oxygen. With those compounds containing no oxygen, it is best to employ an oxidation process, such as roasting on charcoal or in the open tube. Heating in a closed tube is a good method for some compounds. With arsenates it is necessary to employ a reduction process.

Tests for Arsenic in Minerals containing No Oxygen.

1. *Roasting on Charcoal: Coating of Oxide: Arsenical Odor.*—When arsenic, its sulphide, or an arsenide, is heated before the blowpipe on charcoal, volatile products are given off, and the arsenic unites with the oxygen of the air to form As_2O_3, a white, volatile substance, which condenses on the charcoal at a considerable distance from the assay. The fumes that are given off when the assay is heated in the reducing flame have a disagreeable, *garlic-like* odor with which one soon becomes familiar, and which serves as a characteristic test for the identification of the element. The odor is perhaps due to the formation of a little *arseniuretted hydrogen*, AsH_3. It does not come from As_2O_3, for this, when volatilized without reduction, gives no odor.

The tests mentioned above may be very well observed by heating either the powder or fragments of arsenopyrite, FeAsS, on a flat charcoal surface. Note carefully that the sublimate deposits at a considerable distance from the assay, and test its volatility by heating with a blowpipe flame (compare Antimony, p. 44, § 1). In addition to the garlic odor of the arsenic, the sulphur, especially after the assay has been heated for some time, yields a strong pungent odor of SO_2 (p. **119,** § 2), which is entirely different from that of the arsenic, and must not be mistaken for it.

2. *Roasting in the Open Tube.*—When arsenic, an arsenide, or a sulphide of arsenic, is heated in an open tube, a sublimate of white crystalline *arsenious oxide*, As_2O_3, is formed, and condenses as a ring on the sides of the glass. The sublimate is further characterized by being volatile, so that it can be readily driven up and out of the tube by heating. The crystals of As_2O_3 develop best where the glass is rather warm, and by breaking the tube and examining them with a microscope it will be found that they are usually simple, but occasionally twinned, octahedrons.

Heat from $\frac{1}{16}$ to $\frac{1}{32}$ of an ivory spoonful of powdered arsenopyrite, FeAsS, in an open tube, and observe the reactions mentioned above.

$2FeAsS + 10\,O = Fe_2O_3 + 2SO_2 + As_2O_3$. If a yellow deposit of sulphide of arsenic forms, or a black one of arsenic, it indicates that the oxidation has not been made properly; either the substance was heated too rapidly, or there was not a sufficient draft of air passing up the tube to bring about the oxidation (see p. 19).

3. *Heating in the Closed Tube: Arsenical Mirror.*—When arsenic and *some* arsenides are heated in the closed tube, *arsenic* volatilizes and condenses on the cold walls of the tube. When very little deposits, the sublimate appears brilliant black (arsenical mirror); but if much of it is driven off, that which is nearest to the heated end crystallizes and appears gray. If the tube is broken just below the sublimate and heated so that the arsenic volatilizes, the characteristic garlic odor may be observed very distinctly, perhaps better in this way than in any other, and a very little arsenic is sufficient to give it.

Test the above with arsenopyrite, FeAsS. At first, perhaps, a little yellow sulphide of arsenic may be driven off, but the arsenical mirror soon makes its appearance. Owing to the greater affinity of iron for sulphur than for arsenic, the change which the mineral undergoes is essentially as follows: $FeAsS = FeS + As$.

The sulphides of arsenic, realgar, AsS, and orpiment, As_2S_3, when heated in the closed tube, are completely volatilized, condensing at first as a reddish-yellow sublimate, changing to dark red or almost black when hot, and to reddish-yellow when cold.

4. *Special Test for Oxide of Arsenic.*—An exceedingly delicate test, proposed by Berzelius, may be made by placing a little oxide of arsenic at the bottom of a closed tube drawn out as in Fig. 43, and above it, a splinter of charcoal. Heat is first applied at the upper end of the charcoal, until the latter becomes red hot, and then at the lower end, when the oxide of arsenic volatilizes, becomes *reduced* in passing the red-hot charcoal, and condenses above as an arsenical mirror. This method will be found very convenient for testing coatings of oxides, obtained by heating before the blowpipe on charcoal, when there is any doubt as to whether they contain arsenious oxide.

FIG. 43.

It will also be especially useful when it is desired to detect arsenic in the presence of antimony, for the two elements frequently occur together, and both give volatile white coatings on charcoal, but *antimony oxide* gives no mirror when treated as above. It is to be noted, however, that when a considerable quantity of antimony is taken, a trifling dark deposit of some antimony compound may form near the charcoal, but this should not be mistaken for the characteristic arsenical mirror, which forms a considerable distance up the tube. In order to make the test, it is only necessary to scrape up a little of the coating which is farthest away from the assay (a little charcoal powder with it does no harm), and heat in the tube as directed above.

5. *Test with Hydriodic Acid on a Gypsum Tablet.*—Arsenic compounds, when treated according to directions given on p. 17, yield a very volatile orange to yellow coating of iodide of arsenic.

6. *Flame Test.*—If arsenic is volatilized from a mineral by heating before the blowpipe in the *reducing flame*, it imparts to the latter a violet tinge. The color may also be obtained when either arsenic or its sublimate of oxide in a tube is volatilized, so that it passes from the end of the tube into the reducing part of a Bunsen-burner flame.

7. *Oxidation with Nitric Acid.*—Compounds of arsenic, when boiled with *concentrated nitric acid*, are, with few exceptions, oxidized and dissolved, with formation of *arsenic acid*, H_3AsO_4. To detect arsenic in the solution, the methods given beyond under *arsenates* (§ 9, *b*) may be employed.

ARSENATES.

DETECTION.—The reduction of arsenates in the closed tube, with the formation of an arsenical mirror, furnishes the best means of detection. The oxidation and roasting processes used for the detection of arsenic in arsenides and other compounds containing no oxygen *cannot* be applied to arsenates, as they are already oxidized.

1. *Reduction in the Closed Tube: Arsenical Mirror.*—*a.* With few exceptions the arsenates are readily fusible, and for all such the following decisive test may be applied: In a narrow closed tube place a few splinters of charcoal and a fragment of the arsenate, and heat intensely with a blowpipe flame, so that the fused mineral comes in contact with the charcoal. Under these conditions the arsenate is *reduced*, and the arsenic volatilizes and forms an *arsenical mirror*.

b. Provided the arsenate is infusible in the closed tube, and in the absence of easily reducible metals, such as lead, copper, or iron, proceed as follows: Mix a little of the finely powdered mineral with 4 volumes of *dry* sodium carbonate and a little powdered charcoal, transfer to a closed tube, warm gently at first, and then heat intensely in a Bunsen-burner or blowpipe flame. Under these conditions the arsenic, resulting from the reducing action of the charcoal, will volatilize and condense on the glass as an *arsenical mirror*.

c. When the foregoing tests cannot be applied, mix the powdered mineral with about 6 volumes of sodium carbonate, and fuse either in a platinum spoon or on a flat charcoal surface, using an oxidizing flame. The fused material is transferred to a test-tube, boiled for a minute with about 5 cc. of water, in order to dissolve the sodium arsenate resulting from the fusion, and then filtered. To the filtrate hydrochloric acid is added in excess, then an excess of ammonia, which may cause the precipitation of some arsenate, and lastly a little magnesium sulphate solution, in order to precipitate the arsenic as ammonium magnesium arsenate, NH_4MgAsO_4. Filter off the precipitate, dry it by pressing between blotting-paper, mix a little of it with sodium carbonate and charcoal powder, and heat in a closed tube as directed in § *b*. Provided the precipitate is small, place the filter-paper containing it in a porcelain crucible, char the paper by very gentle ignition, and test the charred material, mixed with a little sodium carbonate and charcoal powder, in a closed tube.

Barium, Ba.—Bivalent. Atomic weight, 137.

OCCURRENCE.—Barium is an *alkali-earth metal*, which is found quite abundantly in barite, $BaSO_4$, and in some regions in witherite, $BaCO_3$, but other combinations containing it are seldom met with. It occurs in only a few silicates (hyalophane, harmotome, brewsterite), and sparingly in the igneous rocks of some regions.

DETECTION.—Usually barium may be readily detected by the flame coloration, alkaline reaction, and precipitation as barium sulphate.

1. *Flame Test.*—Barium gives a yellowish-green coloration to the flame, which may sometimes be intensified by moistening the assay with hydrochloric acid. The color cannot be obtained directly from silicates, and must not be mistaken for that of boron and phosphorus.

Make the experiment with barite or witherite, holding fragments in the forceps and heating before the blowpipe. Make the test also by heating some of the powder on a platinum wire, as directed on p. 35.

2. *Alkaline Reaction.*—With the exception of the silicates and phosphates, barium minerals become alkaline upon intense ignition before the blowpipe. A similar reaction is obtained with other minerals containing alkalies and alkaline earths.

Heat fragments of barite or witherite, and place them upon moistened turmeric-paper. For the cause of the alkaline reaction, see Calcium (p. 58, § 1).

3. *Precipitation as Barium Sulphate.*—Barium sulphate, $BaSO_4$, is very insoluble in water and dilute acids, and will be precipitated, therefore, from solutions containing barium, upon the addition of a few drops of *dilute sulphuric acid.* The test is a very delicate one, and will always serve to distinguish compounds containing barium from those containing boron and phosphorus, which may give green flame colorations. It will also serve for the detection of barium in silicates and other compounds.

a. Dissolve ½ ivory spoonful of witherite in 3 cc. of dilute hydrochloric acid, warm if necessary, dilute with from 10 to 15 cc. of water, and add *dilute sulphuric acid,* when a white precipitate will form, which is barium sulphate. This should be collected on a filter-paper, washed with water, and tested on platinum wire, as directed under § 1.

b. To apply this test to silicates, dissolve in hydrochloric acid (after previous fusion with sodium carbonate, if the mineral should happen to be insoluble, see p. 110, § 4), separate the silica, precipitate barium sulphate with sulphuric acid, collect on a small filter, and make a flame test on platinum wire. If both barium and strontium are present, a mixed flame will be obtained, and, after moistening with hydrochloric acid, often the red of strontium will appear strongest at first, while later the green of barium may be seen. In order to obtain decisive results, it may be necessary to make use of a spectroscope.

4. *Specific Gravity.*—On account of the high atomic weight of barium, minerals containing it are characterized by high specific gravities, considerably greater than those of the corresponding strontium or calcium compounds (see p. 118, § 4).

Beryllium, Be.—Bivalent. Atomic weight, 9.

OCCURRENCE.—Although usually regarded as a rare element, beryllium. sometimes called glucinum, Gl, is found in the common mineral beryl, $Be_3Al_2(SiO_3)_6$, and in a number of others which are not very rare; as chrysoberyl, phenacite, leucophanite, helvite, euclase, gadolinite, beryllonite, and herderite.

DETECTION.—There are no satisfactory blowpipe reactions for beryllium, and tests must be made, therefore, in the wet way, which requires some skill in manipulation.

a. If the mineral is a silicate, treat it according to directions given on p. 110, § 4, for the solution of the mineral and separation of silicic acid; then heat the filtrate from the silica to boiling, and precipitate the beryllium with ammonia, which will also cause precipitation of iron, aluminium, and possibly other elements, if present. Ammonia precipitates beryllium hydroxide, which resembles aluminium hydroxide in appearance. This is filtered and washed well with water, transferred together with the paper to some vessel, and warmed with dilute hydrochloric acid in order to dissolve it. The paper is filtered off, and the filtrate evaporated carefully (best in a casserole) until only a drop or two of the acid is left. After cooling, a few drops of water are added to obtain everything in solution, and then a little potassium hydroxide solution, a drop at a time, and just sufficient to dissolve the precipitate of beryllium hydroxide which forms at first. The solution is then diluted with cold water to a volume of at least 50 cc., any precipitate of ferric hydroxide or other material filtered off, and the filtrate boiled for a short time, when, if beryllium is present, a precipitate of beryllium hydroxide will appear. The precipitate, if collected on a filter-paper and ignited, yields beryllium oxide, and this when ignited with cobalt nitrate assumes a not very decisive lavender color.

b. If the mineral is a phosphate, special treatment is needed. The powdered mineral is dissolved in hydrochloric acid (after fusion with sodium carbonate, if necessary); when cold, ammonia is added until a permanent precipitate forms, and then hydrochloric acid, a drop at a time, until the solution becomes clear. To the now nearly neutral, cold, and not too concentrated solution, sodium acetate is added, and the precipitated beryllium phosphate, which may also contain ferric and aluminium phosphates, is filtered and washed. The precipitate is next ignited in a crucible until the carbon of the paper is destroyed, and is then fused in platinum with sodium carbonate, by which treatment sodium phosphate and beryllium oxide are formed. The fusion is then treated with hot water to dissolve the sodium phosphate, the beryllium oxide is collected on a filter-paper and washed, and it is afterwards dissolved in hydrochloric acid and tested with potassium hydroxide, as described under *a.* If it is known that the alkali-earth metals are absent, the mineral may be fused directly with sodium carbonate, and treated like the above sodium carbonate fusion.

Bismuth, Bi.—Trivalent. Atomic weight, 208.

OCCURRENCE.—Bismuth plays the part of a weak basic element and also that of an acid-forming one, and is of rather rare occurrence in minerals. It is found native and as sulphide, selenide, telluride, oxide, silicate, and carbonate. The combinations of its sulphide with sulphides of the metals, the *sulphobismuthites*, are analogous to the sulphantimonites and sulpharsenites.

DETECTION.—Usually bismuth may be readily detected by its reactions on charcoal and by the iodine tests.

1. *Reduction on Charcoal to Metallic Bismuth, and Formation of a Coating of Bismuth Oxide.*—Usually bismuth can be readily reduced from its compounds by mixing ¼ ivory spoonful of the powdered mineral with about 3 volumes of sodium carbonate and heating on charcoal in the reducing flame. The globules of the metal thus obtained are readily fusible and are bright when in the flame, but become covered with a coating of oxide when exposed

to the air. They are brittle, and, if removed from the charcoal and hammered on an anvil, they may flatten to some extent at first, but *cannot* be beaten into a thin sheet like lead. Heated before the blowpipe, bismuth is somewhat volatile, and its vapor passing into the air becomes oxidized, and settles on the coal as a lemon- to orange-yellow coating of bismuth oxide, which is white at a distance from the assay. The coating may be volatilized by heating in both the oxidizing and reducing flames without imparting any color to them. The reactions are quite similar to those of lead, but may be distinguished by the iodine tests.

Make the test by heating any simple bismuth mineral, or the commercial oxide of bismuth, as directed above. A somewhat better idea of the bismuth coating may be obtained by removing a globule of the metal and heating it alone before the blowpipe on a fresh piece of charcoal.

2. *Iodine Tests.*—An excellent test proposed by von Kobell consists in adding to a small portion of the powdered mineral 3 or 4 times its volume of a mixture of potassium iodide and sulphur (p. 26), and heating before the blowpipe on charcoal with a small oxidizing flame, when a coating is produced which is yellow near the assay, and bordered on the outer edges by a brilliant red.

The test on a gypsum plate, made as directed on p. 17, yields a chocolate-brown coating of bismuth iodide, which is changed to a brilliant red by exposing for a short time to the fumes of strong ammonia.

3. *Tests in the Wet Way.*—If the mineral is soluble in hydrochloric acid, evaporate the solution until only a few drops remain, and then pour it into a test-tube about one third full of water, when a white precipitate of bismuth oxychloride, BiOCl, will form, which may be collected on a filter and tested, as in § 1. If the mineral is not soluble in hydrochloric acid, dissolve in nitric, then add excess of hydrochloric acid, concentrate to a small volume and pour into water, as directed above. If the presence of lead is suspected, dissolve in nitric and 2 or 3 cc. of concentrated sulphuric acid, evaporate in a casserole until the nitric acid is all expelled, and,

after cooling, digest with water and filter off the insoluble lead sulphate, which may be tested according to p. 87, § 1. To the filtrate, add ammonia to precipitate bismuth hydroxide, and this, when collected on a filter, may be tested according to § 1.

Boron, B.—Trivalent. Atomic weight, 11.

OCCURRENCE.—Boron is the characteristic, non-metallic element of boric acid, H_3BO_3, and its salts, the borates. The latter are not very common, borax, $Na_2B_4O_7.10H_2O$, being the most important. Boron is also found as a constituent of a number of silicates; as tourmaline, axinite, datolite, and danburite. Boron minerals have usually been formed by the action of vapors given off during igneous activity.

DETECTION.—Boron may be detected by the flame coloration and the test with turmeric-paper.

1. *Flame Test.*—Many boron minerals when heated before the blowpipe impart a green color to the flame. The color is a rather bright one, inclining somewhat to yellow (siskin-green), and must not be confounded with that of barium, from which it may readily be distinguished by other tests.

Minerals which do not give the boron flame when heated alone usually show it when their powder is mixed intimately with about 3 volumes of the potassium bisulphate and fluorite mixture (p. 26), and heated rather gently before the blowpipe or in a Bunsen-burner flame. The mixture is most conveniently introduced into the flame by taking up a little of it on the end of a hot platinum wire or in a small loop. The hydrofluoric acid liberated by the mixture attacks the mineral, forming boron fluoride, BF_3, and this gives a green flame coloration, which is usually of only momentary duration.

Tests may be made with datolite, $Ca(BOH)SiO_4$, or danburite, $CaB_2(SiO_4)_2$, which give a green flame color when heated alone, and also with tourmaline, in which case it is necessary to make use of the potassium bisulphate and fluorite mixture.

2. *Test with Turmeric-paper.*—If turmeric-paper is moistened with a *dilute* hydrochloric acid solution of a mineral containing

boron, and then dried at 100° C. (on the outside of a test-tube containing boiling water), it assumes a reddish-brown color, and this is changed to inky-black by moistening with ammonia. The test is very delicate and satisfactory, and may be applied to all boron minerals, for, if insoluble in acids, they may be dissolved after fusion with sodium carbonate, as directed on p. 110, §§ 3 and 4.

Bromine, Br.—Univalent. Atomic weight, 80.

OCCURRENCE.—This non-metallic element is found very rarely in minerals, the only ones of importance being the silver ores, embolite, AgCl with AgBr, and bromyrite, AgBr. The bromides, salts of hydrobromic acid, are mostly soluble in water.

DETECTION.—Many of the reactions of bromine are similar to those of chlorine and iodine. Silver nitrate precipitates silver bromide, AgBr. When a bromide is heated in a bulb tube with potassium bisulphate and pyrolusite, bromine is liberated, and may be distinguished by the red color of its vapor, and the formation of liquid bromine if the reaction is strong. (Chlorides and iodides when similarly treated yield chlorine gas and iodine, respectively.) Silver bromide, when heated in a closed tube with galena, yields a sublimate of lead bromide, which is sulphur-yellow when hot, and white when cold.

For the detection of bromine in presence of iodine, see p. 69.

Cadmium, Cd.—Bivalent. Atomic weight, 112.

OCCURRENCE.—Cadmium is a rather rare element, and is mostly found associated with zinc in some varieties of sphalerite and smithsonite. Only one cadmium mineral is known, greenockite, CdS.

DETECTION.—If minerals containing cadmium are mixed with sodium carbonate and heated before the blowpipe on a flat charcoal surface in the reducing flame, metallic cadmium is readily formed and volatilized. The element unites with the oxygen of the air, and the resulting oxide collects on the charcoal as a reddish-brown coating, which is yellow distant from the assay, and usually iridescent if only a little of it forms.

In the presence of zinc, the foregoing method may sometimes be employed, since, owing to the ease with which cadmium is reduced and volatilized, its coating will appear before that of zinc. It is better, however, to proceed as follows: Dissolve from 4 to 6 ivory spoonfuls of the mineral in nitric acid, add 1 or 2 cc. of concentrated sulphuric acid, and evaporate in a casserole until the nitric acid is removed. On cooling, add about 100 cc. of water and 10 cc. of hydrochloric acid, filter, and pass hydrogen sulphide gas through the filtrate for half an hour, then filter off the precipitated cadmium sulphide, and wash with water. Place the paper containing the precipitate upon a piece of charcoal, add sodium carbonate, and heat before the blowpipe, first with a small oxidizing flame until the paper is burned, and then in a reducing flame to obtain the coating of cadmium oxide.

Caesium, Cs.—Univalent. Atomic weight, 133.

OCCURRENCE.—This very rare alkali metal has been found in pollucite, $H_2Cs_4Al_4(SiO_3)_9$, and in small quantities in some varieties of lepidolite and beryl. Rubidium is often found with caesium.

DETECTION.—Caesium is similar to potassium, and may be precipitated as caesium platinic chloride, Cs_2PtCl_6 (see p. 106, § 3). The precipitate is much more insoluble than the corresponding potassium compound, separates in a finer condition, and has a paler color. To make sure of its identity, it is best to heat some of the precipitate on a platinum wire, and examine the flame with a spectroscope.

Calcium, Ca.—Bivalent. Atomic weight, 40.

OCCURRENCE.—This alkali-earth metal is found very abundantly in nature (see p. 3). It is a constituent of many silicates and of most rocks, while its combinations with hydrofluoric, carbonic, sulphuric, phosphoric, and other acids are very common. Examples of important calcium minerals are calcite, $CaCO_3$; fluorite, CaF_2; gypsum, $CaSO_4.2H_2O$; pyroxene, $CaMg(SiO_3)_2$; and apatite, $Ca_4(CaF)(PO_4)_3$.

DETECTION.—Usually, the best methods to apply are the alkaline reaction after heating, and the precipitation as calcium sulphate, carbonate, or oxalate.

1. *Alkaline Reaction.* — Calcium minerals become alkaline upon ignition before the blowpipe, with the exception of the silicates, phosphates, borates, and the salts of a few rare acids. A similar reaction is obtained with other minerals containing alkalies and alkaline earths.

a. Heat a fragment of calcite before the blowpipe, and place it upon a piece of moistened turmeric-paper. In this experiment, the heat drives out CO_2 from the calcite, leaving *lime*, CaO, which dissolves to some extent in the water and gives the alkaline reaction.

b. Heat a fragment of fluorite, and place it upon moistened turmeric-paper. In this experiment, water (*one of the products of combustion*) reacts to some extent upon the fluorite, as follows: $CaF_2 + H_2O = CaO + 2HF$.

Fluorite, if heated in a closed tube, would not decompose nor become alkaline.

c. Heat a fragment of gypsum and test on turmeric-paper. In this experiment, the intense heat of the blowpipe flame is perhaps sufficient to drive out SO_3 from $CaSO_4$, although the water resulting from combustion undoubtedly assists very much in bringing about the decomposition (compare p. 81, § 1, where only neutral water is given off by heating gypsum in a closed tube).

2. *Flame Test.*—A few calcium compounds when heated before the blowpipe volatilize to some extent and give a yellowish-red coloration to the flame. The color is often weak, and in testing most calcium minerals it does not appear at all. Since calcium chloride is volatile, the color may often be observed when the assay is heated, after moistening with hydrochloric acid. The flame must not be mistaken for the much redder one of strontium (see p. 116, § 1).

Heat a fragment of calcite in the platinum forceps, and observe that it gives only a very little or no color to the flame; then touch it to a drop of hydrochloric acid and heat again. Better still, mix powdered calcite with a drop of hydrochloric acid, then touch the end of a clean platinum wire to the mixture, and introduce it into a Bunsen-burner or blowpipe flame.

3. *Precipitation as Calcium Sulphate* (*Gypsum*).—As gypsum, $CaSO_4.2H_2O$, is rather insoluble in water, and sparingly so in dilute hydrochloric acid, it may be precipitated from a solution containing calcium upon the addition of a few drops of *dilute sulphuric acid*, provided the solution is neither too dilute nor too strongly acid. If the test is carried out according to the details given below, it will be found a very convenient one for the detection of calcium.

Dissolve 2 ivory spoonfuls of calcite in a test-tube in 3 cc. of hydrochloric acid, divide the solution into 2 parts, dilute one with about 10 times its volume of water, and then add a few drops of *dilute sulphuric acid* to each. The precipitate which forms in the concentrated solution is calcium sulphate, and this will dissolve readily upon addition of water and warming (difference from strontium and barium). No precipitate forms in the dilute solution, owing to the solubility of the calcium sulphate.

4. *Behavior toward Ammonia.*—Calcium is not precipitated from solutions upon addition of ammonia, except when carbonic, phosphoric, silicic, boric, or other acids are present with which calcium forms insoluble compounds. This behavior is very important, for often other elements which are present with calcium in a solution may be precipitated by means of ammonia, separated by filtration, and the calcium detected in the filtrate by the tests given beyond.

a. Dissolve an ivory spoonful of calcite in a test-tube in 3 cc. of dilute hydrochloric acid, boil for a few seconds to expel CO_2, dilute with about 10 cc. of water, and add an excess of ammonia; i.e., until the solution smells of ammonia, or shows a blue color with litmus-paper. If the calcite should be impure, traces of foreign substances may be precipitated, but no calcium will be thrown down. Save the solution for experiments under §§ 5 and 6.

b. Dissolve an ivory spoonful of apatite, calcium phosphate, in a test-tube, in 3 cc. of hydrochloric acid, dilute with water, and add ammonia in excess. In this experiment, the precipitate which forms is calcium phosphate, and this, although soluble in acids, is *insoluble* in neutral or alkaline solutions.

5. *Precipitation as Calcium Carbonate.*—Ammonium carbonate added to a solution made strongly alkaline with ammonia precipitates calcium carbonate, $CaCO_3$. If made from a boiling solution, the precipitation is practically complete, and the calcium can be removed by filtering.

6. *Precipitation as Calcium Oxalate.*—Ammonium oxalate added to an alkaline or even slightly acid solution precipitates calcium oxalate, CaC_2O_4. The test is very delicate, and the separation complete, but the precipitate comes down in a very finely divided condition, and is apt to run through a filter-paper. It may almost always, however, be readily filtered if the precipitation is made in a hot solution, and then allowed to stand for an hour before filtering.

The following method may sometimes be found convenient for the detection of calcium in phosphates: Dissolve an ivory spoonful of the powdered mineral in a test-tube in 3 cc. of hydrochloric acid, add ammonia until a precipitate forms, and then hydrochloric acid, a drop at a time, until the solution becomes clear. Dilute now with about 10 cc. of water, and add ammonium oxalate, when, if calcium is present, it will be precipitated from the *slightly acid* solution as oxalate. The above may be tested with apatite.

7. *For the detection of calcium in silicates and complex bodies*, see p. 110, § 4.

Carbon, C.—Tetravalent. Atomic weight, 12.

OCCURRENCE.—Diamond and graphite are crystallized forms of carbon, and anthracite coal is also nearly pure carbon. Bituminous coal, asphalt, paraffin, mineral oils, and many natural gases are different forms of *hydrocarbons;* i.e., combinations of carbon and hydrogen, for which usually no definite chemical formulae can be given, and which cannot, therefore, be classed as definite mineral species. The carbonates, salts of carbonic acid, H_2CO_3, form a very important class of minerals, including such common ones as calcite and aragonite, $CaCO_3$; dolomite, $CaMg(CO_3)_2$; siderite, $FeCO_3$, and many others.

DETECTION.—The burning of carbon with formation of carbon dioxide, and the closed-tube reactions serve for the detection of the different forms of coal, hydrocarbons, and organic substances. For *carbonates*, effervescence with acids is usually a sufficient test.

Carbon, Anthracite and Bituminous Coals, Hydrocarbons, and Organic Matter.

Closed-tube Reactions.—Hydrocarbons, bituminous coals, and organic matter, when heated in a closed tube, usually suffer destructive distillation. Tar-like substances, oils, water, and gas are given off, and condense in the tube, while a strong empyreumatic odor may usually be observed. The residue, if any is left, is generally nearly pure carbon. Anthracite coal and the different forms of nearly pure carbon suffer no change when heated in a closed tube, except that perhaps a little water is driven off.

a. To show the effect of organic matter, heat a small fragment of wood in a closed tube.

b. Partly fill a bulb tube or a large closed tube with bituminous coal, draw out the upper end, as in Fig. 44, then apply heat to the bulb, and set fire to the escaping gas. If the residue left in the tube forms a hard, coherent, vesicular mass it would indicate a *coking coal,* while if soft and pulverulent, it would indicate a *non-coking coal.*

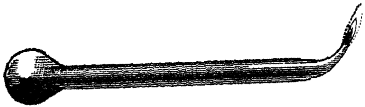


Fig. 44.

c. Partly fill a bulb tube or a large closed tube with pyrolusite, MnO_2, carefully shove a piece of anthracite coal to a position near the pyrolusite, *a,* Fig. 45, and apply heat, first to the coal until it becomes red hot, then to the pyrolusite. As oxygen is driven from the pyrolusite, the coal will burn, and continue to glow as long as the supply of oxygen lasts or any of the coal remains (compare p. 100, § 1).

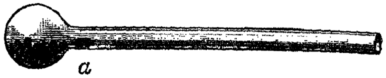


Fig. 45.

Graphite is a form of carbon which burns with great difficulty, and cannot be tested as above, while diamond burns quite readily, provided that part of the glass where the diamond is located is heated intensely so as to start the combustion.

Carbonates.

1. *Effervescence with Acids.*—When carbonates are dissolved in acids, carbon dioxide gas, CO_2, is given off with effervescence. The carbonates are salts of a weak acid, and when treated with a strong acid they are decomposed, yielding salts of the stronger, and setting the weaker acid free. Theoretical carbonic acid is H_2CO_3, but when liberated it splits up into H_2O and CO_2. Therefore, the reaction between calcium carbonate and hydrochloric acid may be represented as follows: $CaCO_3 + 2HCl = CaCl_2 + H_2O + CO_2$. Any strong acid (hydrochloric, nitric, or sulphuric) may be used to liberate carbon dioxide, by *strong* being meant one with strong chemical affinity, not a concentrated acid. The reaction usually succeeds best when dilute hydrochloric acid is used, and it may take place in the cold, although sometimes it is necessary to apply heat. When heat has to be applied, care must be taken not to mistake boiling and escaping bubbles of steam for carbon dioxide. Carbon dioxide is characterized by being a heavy, colorless, and odorless gas, which is not apt to be confounded with other gases. It does not support com-

bustion, and, when brought in contact with clear barium hydroxide solution, it gives a white precipitate of barium carbonate. $CO_2 + BaO_2H_2 = BaCO_3 + H_2O$.

a. Take 2 ivory spoonfuls of powdered calcite in a test-tube, add a little water and an equal quantity of hydrochloric acid, when an effervescence will be observed, and the air will soon be displaced by the heavier carbon dioxide, if the tube is held vertically. A burning match, if thrust into the tube, will be immediately extinguished. Pour a little barium hydroxide solution into a second test-tube, and, holding the two tubes mouth to mouth, incline the one containing the carbon dioxide, so that the heavy gas can pour down into the one containing the barium hydroxide, when, on shaking the latter, a white precipitate of barium carbonate will appear. It is evident that the test with barium hydroxide, made as suggested above, can be used only when carbon dioxide is abundantly given off and the tube is filled with the gas.

A more delicate method of testing with barium hydroxide is to make use of a tube like the one shown in Fig. 46. Fragments of the carbonate to be tested are placed in the lower bulb, and, by means of a pipette, dilute acid is introduced, care being taken not to allow any of it to get into the upper bulb, or on the sides of the tube above the latter. The tube being held nearly horizontal, barium hydroxide is then introduced into the upper bulb, where a precipitate of barium carbonate will be formed by the escaping carbon dioxide.

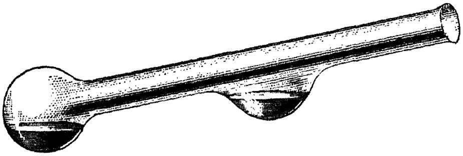


FIG. 46.

Effervescence may be detected in a minute particle of mineral by bringing the latter in contact with a drop of acid on a watch-glass or in a test-tube.

b. Take some dolomite, $CaMg(CO_3)_2$, and treat it exactly as described under *a*, and it will be observed that only a very slight or no effervescence takes place in the cold, but, on warming, carbon dioxide is abundantly given off. In testing carbonates which are soluble only in hot acids, it is best to have the mineral finely pulverized. Care must always be taken not to mistake boiling for effervescence.

c. The mistake is sometimes made of testing carbonates with acids which are too concentrated, as illustrated by the following experiments: In dry test-tubes treat fragments of witherite, $BaCO_3$, with concentrated hydrochloric acid, and cerussite, $PbCO_3$, with concentrated nitric acid, and, in both cases, there will be only a very trifling or no effervescence, owing to the insolubility of barium chloride and lead nitrate in the respective acids. On dilution with 2 or 3 volumes of water, however, effervescence will commence, because the salts which form on the outside of the fragments dissolve, and thus fresh surfaces of the carbonates are constantly exposed to the action of the acids.

d. In order to show that there is sometimes danger of overlooking a small quantity of a carbonate, test as follows: Dissolve from $\frac{1}{8}$ to $\frac{1}{4}$ of an ivory spoonful of sodium carbonate in 5 cc. of cold water, and add a little hydrochloric acid, when no or only a slight effervescence will be visible, owing to the fact that carbon dioxide is soluble to some extent, and remains dissolved in the liquid. On heating, the gas makes its appearance.

2. *Decomposition by Heating: Closed-tube Reaction.*— Carbonates when heated are usually decomposed, carbon dioxide going off and oxides of the metals being left. An exceedingly delicate test may be made by heating a small particle of a carbonate in a closed tube, and testing for the presence of carbon dioxide, by bringing a little barium hydroxide solution into the upper end of the tube by means of a capillary pipette.

The ease with which carbonates decompose depends upon the character of the metals with which the carbonic acid radical is in combination. Carbonates of the metals with strong chemical affinity, such as potassium or sodium, are not decomposed at a red heat, while those with weak chemical affinity, like iron or zinc, decompose at a moderate temperature. Calcium occupies an intermediate position, and calcite, or limestone, $CaCO_3$, is not decomposed at a low red heat, but is wholly converted by intense ignition into CaO, as illustrated by the familiar example of burning lime. $CaCO_3 = CaO + CO_2$.

Make the experiment by heating a small fragment of siderite, $FeCO_3$, in a closed tube, and observe that the brown, non-magnetic mineral is changed to black magnetic oxide of iron, while the carbon dioxide in the tube may be detected by means of barium hydroxide.

Cerium, Ce.—Usually trivalent, but tetravalent in *ceric* compounds. Atomic weight, 140.

In connection with cerium it will be well to consider a number of other elements, known as the *Rare Earth Metals.* The more important of these are lanthanum, La; didymium, Di; yttrium, Y; erbium, Er; and thorium, Th. This group, however, has been further subdivided, so that it now includes gadolinium, neodymium, praseodymium, samarium, scandium, terbium, thulium, and ytterbium, but the reactions for these rare substances are so obscure and difficult that no attempt will be made to give them in the present work.

OCCURRENCE.—The rare earths are usually found associated with one another, and minerals containing essentially the cerium group (Ce, La, and Di) are cerite, allanite, monazite, fergusonite, samarskite, tysonite, parisite, and bastnaesite. The yttrium earths (Y and Er) are found especially in gadolinite, xenotime, yttrotantalite, euxenite, polycrase, and sipylite. Thorium is found in thorite, monazite, aeschynite, polymignite, and thorogummite.

DETECTION.—The rare earths are all precipitated as hydroxides from acid solutions by means of ammonium or potassium hydroxides, but this precipitation may be often omitted when it is known that calcium is absent. The precipitate when filtered and washed is dissolved in hydrochloric acid, the excess of acid removed by evaporation, the residue dissolved in water, and oxalic acid added, when a precipitate of oxalates of the earths will be thrown down, which is insoluble in oxalic acid. The precipitate when filtered, washed, and ignited, yields oxides of the earths.

In order to detect thorium, the oxides are dissolved by boiling with a few cc. of dilute sulphuric acid, the solution evaporated, transferred finally to a crucible, and heated carefully until the excess of sulphuric acid is wholly driven off, thus converting the earths into normal sulphates. The sulphuric acid must be driven off in a good draft, for the fumes are very irritating, and in order to regulate the heat it is best to place the crucible containing the sulphates inside a porcelain one, thus leaving an air space between, and to adjust the heat so that the outer crucible is not heated above faint redness. The crucible should be covered toward the end of the operation, and the heating continued until no white fumes appear when the cover is raised. If the sulphates have been properly heated, they should be wholly soluble in cold water, and thorium may then be precipitated from the dilute solution by adding sodium thiosulphate, $Na_2S_2O_3$, and boiling. The precipitate, when collected on a filter-paper, washed, and ignited, yields thorium oxide, ThO_2. Zirconium, if present, will precipitate with thorium, and, from solutions which are too concentrated, cerium may also be precipitated. To make certain, therefore, of the identity of the thorium, it will be best to convert the ignited material again into sulphate, and to repeat the precipitation with sodium thiosulphate.

In order to detect the remaining groups, the earths contained in the filtrate from the thorium are precipitated by means of oxalic acid, and converted into sulphates, as directed above. The sulphates are then dissolved in a little cold water, and about 2 volumes of a boiling, saturated solution of potassium sulphate are added, which precipitates Ce, La, and Di completely, as double potassium sulphates, $Ce_2(SO_4)_3 + 3K_2SO_4$, while Y and Er remain in solution. After standing a few hours in the cold, the precipitate may be filtered, and washed with a cold saturated solution of potassium sulphate. From the filtrate, Y and Er may be then precipitated by means of ammonium oxalate, while the precipitate containing Ce, La, and Di, may be dissolved in hot hydrochloric acid, and the earths precipitated by addition of ammonium oxalate and ammonia. The detection of the separate elements in the two groups is a difficult matter, and is usually not very important. Ce, La, and Di almost invariably occur together, while Y and Er are usually associated with one another.

In the cerium group, pure ignited oxide of cerium, CeO_2, is nearly white, as are also the oxides of lanthanum, La_2O_3, and didymium, Di_2O_3, but a mixture of cerium oxide with the latter always has a brown color. If the solution of the ignited oxides in sulphuric acid is yellow, it indicates cerium, and is due to ceric sulphate, $Ce(SO_4)_2$. After igniting the sulphates, however, cerous sulphate, $Ce_2(SO_4)_3$, is formed, which gives a colorless solution. If the oxides are dissolved in a borax bead in the oxidizing flame a brownish-red or yellow bead, fading to yellow on cooling, indicates cerium. In the reducing flame, the bead becomes colorless or nearly so. With phosphorus salt, the colors for cerium in the oxidizing flame are yellow when hot, fading to colorless when cold, and in the reducing flame, colorless both when hot and cold. When cerium does not interfere, didymium may be detected by means of the borax or salt of phosphorus beads, for when a considerable quantity is dissolved it imparts to them a pale rose color in both the oxidizing and reducing flames. Didymium also imparts to solutions a pale rose color, which may be seen when they are concentrated. If a solution is held before the slit of a spectroscope directed toward a strong light, or if the oxalate precipitate is held in a strong light and examined with a spectroscope, dark bands may be seen interrupting the continuous spectrum, which are known as *absorption bands*, and indicate the presence of the didymium group among the elements precipitated by potassium sulphate. A prominent band is located in the yellow, and another about the middle of the green.

Yttrium gives no absorption spectrum, but erbium and the rare earths related to it give a series of strong absorption bands.

Chlorine, Cl.—Univalent. Atomic weight, 35.5.

OCCURRENCE.—Chlorine is the characteristic non-metallic element of hydrochloric acid, HCl, and the chlorides. With the exception of silver, lead, and mercurous chlorides, the simple chlorides of the metals are soluble in water, and their occurrence, therefore, as minerals is rather restricted, since they cannot occur where water is abundant. Of the soluble chlorides, halite, NaCl; sylvite, KCl; and carnalite, $KMgCl_3.6H_2O$; and of the insoluble ones, cerargyrite, AgCl, are the most important minerals. A number of combinations of chlorides with oxides or hydroxides of the metals, called *oxychlorides*, are known, and chlorine is frequently found in combination with other acids, especially silicic and phosphoric, and is then often isomorphous with fluorine and hydroxyl. Examples are atacamite, $Cu_2Cl(OH)_3$ or $CuCl_2 + 3Cu(OH)_2$; sodalite, $Na_4(AlCl)Al_2(SiO_4)_3$; and pyromorphite, $Pb_4(PbCl)(PO_4)_3$.

DETECTION.—The most satisfactory tests for chlorine are precipitation as silver chloride, or the formation of chlorine gas.

1. *Precipitation as Silver Chloride.*—Silver chloride, AgCl, is very insoluble in water and dilute nitric acid. A very delicate test may therefore be made by dissolving a chloride in water or dilute nitric acid, and precipitating silver chloride by adding a few drops of a solution of silver nitrate. Bromine and iodine give similar reactions. If much chlorine is present, a white, curdy precipitate forms, or, if a trace is present, there is at first only a bluish-white opalescence. On exposure to light, the precipitate soon acquires a violet color.

In order to apply this test to minerals which are insoluble in acids, first fuse with sodium carbonate, as directed under silicates (p. 110, § 4), soak out the fusion with water and dilute nitric acid, filter if necessary, and then add silver nitrate.

To illustrate this test, dissolve ¼ ivory spoonful of halite (common salt) in a few cc. of water, and then add a few drops of nitric acid and of silver nitrate. $NaCl + AgNO_3 = AgCl + NaNO_3$. Test the solubility of the precipitate in an excess of ammonia.

2. *Evolution of Chlorine.*—A very satisfactory test in the dry way may be made by mixing the powdered chloride with about 4 times its volume of potassium bisulphate and a little powdered pyrolusite, MnO_2, and heating the mixture either in a bulb tube or a small test-tube, when chlorine gas will be given off, and may be recognized by its pungent odor or its bleaching action on a strip of moistened litmus-paper held inside the tube (compare p. 101, § 2).

Insoluble compounds, such as silver chloride or a silicate, should first be fused with sodium carbonate, the fusion pulverized, and then treated as above.

3. *Flame Test.*—Chloride of copper is volatile before the blowpipe, giving an azure-blue and sometimes a green coloration to the flame (compare Copper, p. 72, § 1). To use this behavior for the detection of chlorine, Berzelius recommended the following treatment: To a small salt of phosphorus bead add copper oxide until the bead is dark and opaque, then touch it while hot to the substance to be tested, and heat before the blowpipe in an oxidizing flame, when chloride of copper will volatilize and impart a blue color to the flame. The test answers very well for most chlorides, but is not sufficiently delicate for the detection of small quantities of chlorine in minerals. Bromine gives a similar reaction.

4. To distinguish silver chloride, silver bromide, and silver iodide from one another, the following method will be found very convenient: Heat a fragment of the mineral and a little pure, pulverized galena together in a closed tube, and observe the color of the sublimate formed. Silver chloride yields lead chloride, and this fuses on the hot glass to colorless globules which become white when cold. Silver bromide yields lead bromide, which is sulphur-yellow when hot and white when cold. Silver iodide yields lead iodide, which is dark orange-red when hot and lemon-yellow when cold. If iodine is detected by the foregoing test, bromine and chlorine may also be present, and, if iodine is absent, the reaction for bromine will obscure that of chlorine.

5. The detection of chlorine in the presence of bromine and iodine is not a simple matter. If combined with silver, place the material in a test-tube with some granulated zinc, add dilute sulphuric acid, allow the reduction to proceed for some minutes, and then filter or decant the solution of zinc salts from the insoluble silver. Take a few drops of the solution in a test-tube, add some starch paste (a little starch boiled up with considerable water), and then a little, red, fuming nitric acid, when, if iodine is present, it will impart a deep blue color to the starch. To the blue solution add chlorine water drop by drop, which at first sets iodine free, but, when added in excess, combines with it to form a colorless compound. Continue, therefore, to add the chlorine water until the color of iodine disappears, when, if bromine is absent, the solution will be colorless, but, if present, it will be yellowish-red, owing to liberated bromine. This color shows more distinctly when the liquid is agitated with carbon disulphide, which dissolves the bromine.

For the detection of chlorine, provided bromine and iodine are present, take another portion of the solution, add silver nitrate and a little nitric acid, and then filter off and wash the precipitate, which may contain $AgCl$, $AgBr$, and AgI. Transfer this to a beaker, treat with ammonia to dissolve $AgCl$ and $AgBr$, filter from the insoluble AgI, then precipitate the silver salts from the filtrate by addition of nitric acid, and collect them on a filter. Mix the moist precipitate on charcoal with a little more than its volume of sodium carbonate, fuse before the blowpipe, cut away the fusion, treat it with hot water, filter the soluble sodium chloride and bromide from the silver, and evaporate the filtrate to dryness in a dish or casserole. Grind the dried residue with an equal volume of potassium dichromate, transfer to a tubulated test-tube, Fig. 47, add a little concentrated sulphuric acid, close with a stopper, and warm, when, if chlorine is present, it forms with the chromium a red gas, $CrCl_2O_2$, which condenses to a liquid of the same color, while bromine forms red vapors of bromine. If some of the red vapors are distilled over into a second test-tube, and are then treated with a little ammonia, the bromine will be converted wholly into colorless compounds, while the $CrCl_2O_2$ will yield ammonium chromate, which is yellow. The yellow color of ammonium chromate in the second test-tube is, therefore, a proof that chlorine was present.

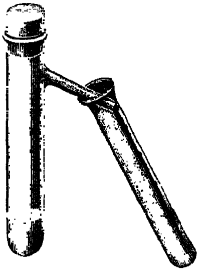


Fig. 47.

Chromium, Cr.—Trivalent and sexivalent. Atomic weight, 52.5.

Occurrence.—Chromium is not a very abundant element, and the mineral from which nearly all its commercial compounds are made is chromite, $FeCrO_4 = FeO.Cr_2O_3$. The element is found, in small quantities, in some varieties of spinel, garnet, muscovite, beryl, clinochlore, and other minerals where Cr_2O_3 is isomorphous with Al_2O_3 or Fe_2O_3. Of the chromates, crocoite, $PbCrO_4$, is the commonest.

DETECTION.—The colors which chromium imparts to the fluxes usually serve for its detection.

1. *Test with a Borax Bead.*—If a very little oxide of chromium is dissolved before the blowpipe in a borax bead in the oxidizing flame, the bead will be decided yellow when hot, changing to yellowish-green when cold. With more of the oxide, the colors are deeper, red when hot, changing through yellow to a fine yellowish-green when cold. After heating in the reducing flame, as soon as the bead cools below a red heat, it assumes a fine green color, and shows none of the yellow which is so prominent after heating in the oxidizing flame. It is probable that the color produced in the oxidizing flame depends upon the presence of CrO_3, the anhydride of chromic acid, salts of which are yellow or red; while in the reducing flame the basic oxide Cr_2O_3 is formed, which usually imparts an intense green color to solutions.

2. *Test with Salt of Phosphorus.*—The colors which are obtained in the oxidizing flame with this flux are dirty green when hot, changing to fine green when cold. After reduction, the colors are about the same as in the oxidizing flame, but not so decided.

Chromium must not be confounded with vanadium, which gives in the reducing flame almost identical reactions with the fluxes, but in the oxidizing flame differs in yielding a yellow bead with salt of phosphorus, which flux never acquires other than a green color with chromium.

3. *Special Tests for Small Quantities of Chromium when Associated with other Substances which Color the Fluxes.*—If the mineral is a silicate, fuse it in a platinum spoon with about 4 volumes of sodium carbonate and 2 of potassium nitrate, by which means an alkali chromate, soluble in water, will be formed. Soak out the fusion in a test-tube with about 5 cc. of water, filter, and, if chromium is present, the filtrate will have a yellow color. Make the filtrate slightly acid with acetic acid, filter again if neces-

sary, and add a little lead acetate, when a yellow precipitate of lead chromate will form, which may be collected on a filter, washed with water, and tested with the fluxes (compare Vanadium, p. 130, § 2). If the precipitate is very small, it will be best to burn the paper in a porcelain crucible and test the residue.

If the mineral is an oxide difficult to decompose, as some kinds of spinel or chromite, dissolve as much as possible of the very finely powdered mineral before the blowpipe in a borax bead, remove the latter from the wire, crush it in a diamond mortar, then mix with 2 or 3 volumes of sodium carbonate and 1 of potassium nitrate, fuse in a platinum spoon, and proceed exactly as described in the previous paragraph.

Cobalt, Co.—Bivalent. Atomic weight, 59.

Occurrence.—Cobalt is a comparatively rare element, found usually in combination with sulphur or arsenic, and generally associated with nickel and iron, with which it is isomorphous. A few of its more important compounds are linnaeite, Co_3S_4; smaltite, $CoAs_2$; cobaltite, CoSAs; and erythrite, $Co_3(AsO_4)_2.8H_2O$.

Detection.—The blue color which cobalt oxide imparts to the fluxes serves as a very simple and delicate means for its detection.

1. *Test with the Fluxes.*—Oxide of cobalt is soluble before the blowpipe both in the borax and salt of phosphorus beads, imparting to them a fine blue color, which remains the same in both the oxidizing and reducing flames. The test is so delicate that cobalt can be detected in the presence of a considerable quantity of iron and nickel.

When copper or nickel interferes with the test for cobalt, remove the bead from the wire, and fuse it on charcoal with a granule of tin in a strong reducing flame, until the copper and nickel are reduced to the metallic state, when the flux will show the blue color of cobalt.

See also the special method for treating minerals containing cobalt, nickel, iron, and copper (p. 97, § 4).

Columbium, Cb.—See *Niobium.*

Copper, Cu.—Bivalent in cupric and univalent in cuprous compounds. Atomic weight, 63.4.

Occurrence.—Copper is widely distributed in nature and is found in a great many minerals. A few of its most important compounds are chalcopyrite, $CuFeS_2$; chalcocite, Cu_2S; bornite, Cu_3FeS_3; tetrahedrite, essentially $Cu_8Sb_2S_7$; malachite, $(CuOH)_2CO_3$; and cuprite, Cu_2O. Copper also occurs in the native state abundantly in a few localities.

DETECTION.—The flame coloration, the formation of globules of metallic copper, and the colors imparted to fluxes and to solutions make the detection of copper a very easy matter.

1. *Flame Tests.*—If finely divided oxide of copper is introduced into a colorless flame, it imparts to it an emerald-green color, which may sometimes be observed on heating minerals before the blowpipe, but often no color is obtained because no volatile compound of copper is present. If the assay is moistened with hydrochloric acid, however, copper chloride, which is volatile, will be formed, and this gives a strong azure-blue color to the flame, tinged usually on the outer edges with emerald-green, due to the decomposition of the chloride and formation of copper oxide. The flame test for copper after moistening with hydrochloric acid is very delicate, but if the mineral is a sulphide, it should be fused in the oxidizing flame or roasted before applying the acid.

a. Take a piece of chalcopyrite in the platinum forceps, heat it before the blowpipe in the oxidizing flame, then touch it to a drop of hydrochloric acid, and heat again. The copper chloride soon volatilizes, but the flame may be repeatedly obtained by renewed applications of acid.

The test may also be made on platinum wire, according to directions given on p. 35.

b. Roast a little powdered chalcopyrite on charcoal, as directed on p. 39, then moisten the product with a drop of hydrochloric acid, and heat before the blowpipe in the reducing flame. In this experiment, the azure-blue flame of copper chloride is obtained in great perfection, and the surface of the charcoal near the assay will show the copper reaction if touched with the reducing flame. A beautiful emerald-green flame is obtained if the assay is moistened with hydriodic instead of hydrochloric acid, and heated before the blowpipe.

c. In order to show the green flame color given by oxide of copper, take a little malachite or cuprite in a diamond mortar, and pulverize it by striking with a hammer in close proximity to a Bunsen-burner flame, so that the fine dust from the mortar will pass into the flame.

2. *Reduction on Charcoal to Metallic Copper.*—From copper oxides and minerals containing oxide of copper, the metal may be readily reduced and obtained as fused globules by heating intensely in a reducing flame, with a flux, on charcoal. Copper globules are bright when covered with the reducing flame, but acquire a coating of black oxide on exposure to the air. They are malleable, can be flattened by hammering on an anvil, and show the red color characteristic of copper. The best **flux** to use is a mixture of equal parts of sodium carbonate and borax: This serves to keep iron and other difficultly reducible metals in solution, as in a slag, while copper may easily be reduced and fused to a globule. Minerals containing sulphur, arsenic, or antimony should first be carefully roasted, according to directions given on p. 39, then mixed with the appropriate flux, and reduced. It is evident that, when other readily reducible metals are present, a globule will be obtained which is not pure copper.

As beginners usually have some difficulty in fusing copper before the blowpipe on charcoal, it is best to use only a small quantity of the mineral and flux. About $\frac{1}{8}$ to $\frac{1}{4}$ ivory spoonful of the mineral and two or three times as much flux will be found to be a suitable quantity.

Obtain globules of copper from malachite, using a mixture of sodium carbonate and borax as a flux, and from chalcopyrite, which must first be roasted and afterwards fluxed with a mixture of sodium carbonate and borax.

3. *Reactions with the Fluxes.*—Copper oxide dissolves readily both in the borax and salt of phosphorus beads on platinum wire. In the oxidizing flame, the colors are green when hot, but change to blue when cold. The color is due to the presence of cupric oxide, CuO, and the test is very delicate. In the reducing flame, the colors are paler, almost colorless, with little copper; while if much is present, there is a separation of cuprous oxide, Cu_2O, when the fluxes solidify, which renders the beads opaque and red by reflected light. A still better way to show this reduction is to remove the bead from the wire, and, placing it on charcoal with a small grain of tin, to fuse the two together in a reducing flame. The bead

will then be clear and nearly colorless when hot, but opaque and red on solidifying. The action of the tin is to take oxygen from the cupric oxide, changing it to cuprous oxide. The reaction succeeds best with the salt of phosphorus bead, and the heating on charcoal in either case must not be too hot nor continued too long a time, as the copper may thus be reduced to the metallic state.

4. *Color of Solutions: Test with Ammonia.*—If a mineral containing copper is dissolved in an acid (usually nitric or hydrochloric is best), the solution will be colored blue or green. On dilution with water and addition of ammonia in excess, the color becomes deep blue, owing to the formation of a complex cuproammonium salt. The test is a very good one for copper, but the color must not be confounded with the similar but much fainter blue given by solutions containing nickel when similarly treated.

a. To make this test, dissolve ½ ivory spoonful of malachite in a test-tube, in 3 cc. of hydrochloric acid, dilute with 10 cc. of water, and add excess of ammonia.

b. Dissolve ½ ivory spoonful of powdered chalcopyrite in a test-tube, in 3 cc. of nitric acid, boil until red fumes cease to appear, dilute with 10 cc. of water, and add ammonia in excess. In this experiment, the formation of a precipitate of ferric hydroxide (p. 87, § 5) may at first prevent the blue color from being seen, but by allowing the precipitate to settle, or better by filtering it off, the color shows distinctly.

5. *Cuprous Compounds.*—Besides the sulphides and the closely related arsenides, tellurides, and selenides, there are very few minerals which are *cuprous* compounds, cuprite, Cu_2O, being the only common one.

A quantitative analysis is the only means available for proving that, in combinations with sulphur, copper exists in the cuprous condition. If it is demonstrated, for example, that the atomic ratio of copper to sulphur is 2 : 1 (see p. 6), the compound must be Cu_2S, or cuprous sulphide.

To illustrate the reactions of cuprous oxide, dissolve an ivory spoonful of powdered cuprite in 3 cc. of hot hydrochloric acid. Observe that the solution is nearly colorless or brown, and not blue, as with cupric compounds. Cool the liquid, and then add a large excess of cold water, when a white precipitate of cuprous chloride, $CuCl$, will be thrown down, which is only sparingly soluble in water and dilute acids. The precipitate is soluble in excess of ammonia, and, if oxidation has been avoided, the intense blue color characteristic of cupric compounds (§ 4) will *not* be obtained, although some of the copper may have become changed to the cupric condition, owing to the oxidizing action of the air.

Didymium, Di.—Trivalent. Atomic weight, 142.

Erbium, Er.—Trivalent. Atomic weight, 166.

The reactions of these rare earth-metals are given under Cerium.

Fluorine, F.—Univalent. Atomic weight, 19.

OCCURRENCE.—Fluorine is the characteristic non-metallic element of hydrofluoric acid, HF, and the fluorides. The number of fluorides that have been identified as minerals is not very large, fluorite, CaF_2; and cryolite, Na_3AlF_6, being the most important. Fluorine is found frequently as a constituent of silicates and phosphates, as in topaz, $(AlF)_2SiO_4$; chondrodite, $Mg_3[Mg(F.OH)]_2(SiO_4)_2$; apatite, $Ca_4(CaF)(PO_4)_3$; and amblygonite, $Li(AlF)PO_4$, and, in such compounds, hydroxyl and occasionally chlorine are isomorphous with, and partially replace, the fluorine.

DETECTION.—The etching of glass and the formation of volatile compounds with silicon furnish the best methods for the detection of fluorine.

1. *Etching of Glass.—This test is applicable only to compounds, other than silicates, which are decomposed by sulphuric acid.* If without a platinum crucible, prepare some small pasteboard trays or box-covers by placing them in melted paraffin and allowing them to remain until the paper is thoroughly permeated; then, leaving several drops of paraffin in the bottom of each, place them to one side on a sheet of paper to cool. At the same time some pieces of window glass, larger than the tops of the boxes, may be coated with paraffin by dipping them in the melted material and allowing them to cool. To make a test for fluorine, in a platinum crucible or one of the prepared trays put an ivory spoonful of the finely powdered mineral and 3 or 4 drops of concentrated sulphuric acid, mix the two together and cover with one of

the prepared glass plates on the under side of which lines have been traced through the paraffin with some pointed instrument. The action of sulphuric acid on the fluoride liberates hydrofluoric acid, HF, which attacks the silica, SiO_2, of the glass wherever it is not protected by the paraffin; thus, $4HF + SiO_2 = SiF_4 + 2H_2O$. For a successful experiment the etching should be allowed to proceed for at least one half hour, or longer if the amount of fluorine is small. The presence of fluorine is revealed by a distinct etching of the glass, seen best after warming the plate and cleaning off the paraffin with a bit of paper or cloth.

Make the experiment with fluorite, CaF_2, when the decomposition with sulphuric acid may be expressed as follows: $CaF_2 + H_2SO_4 = CaSO_4 + 2HF$.

2. *Test with Potassium Bisulphate.*—This test is applicable only to compounds which are decomposed by fusion with the reagent. Mix some finely powdered fluoride with an equal volume of powdered glass and 2 or 3 volumes of potassium bisulphate, then put not over ½ ivory spoonful of this mixture in a closed tube of 6 mm. internal diameter and heat gently. The hydrofluoric acid liberated by the reaction attacks the glass, $4HF + SiO_2 = SiF_4 + 2H_2O$, and at the place where the water condenses a second decomposition occurs, as follows: $3SiF_4 + 2H_2O = 2H_2SiF_6$ (hydrofluosilicic acid) $+ SiO_2$. The separated silica, SiO_2, forms a white ring in the tube, which is volatile as long as hydrofluosilicic acid is present, but on breaking the tube just above the fusion and washing away the hydrofluosilicic acid from the upper portion with water, and then drying, the silica will no longer be volatile. The etching of the tube is not a conspicuous feature of this test, but the ring of silica is very characteristic, especially its behavior before and after washing with water.

3. *Test with Sodium Metaphosphate.*—This test will often be found convenient, since *it can be applied to minerals which are not decomposed by sulphuric acid.* If the finely powdered mineral is mixed with from 4 to 6 parts of sodium metaphosphate, transferred to a bulb tube (which should not be more than one quarter full) and heated very hot, hydrofluoric acid will be given off, which etches the glass, and deposits a ring of silica exactly as described

in § 2. The test is excellent for silicates when the proportion of fluorine is not too small (less than 5 per cent), but when very small quantities are to be detected the method given in § 4 is preferable.

Sodium metaphosphate may be prepared by heating phosphorus salt in a platinum dish until ammonia and water are expelled, or a sufficient quantity for an experiment may be quickly made by fusing beads of phosphorus salt on platinum wire, and crushing them in a diamond mortar. To make the experiment, test for fluorine in topaz. The reaction with topaz cannot be expressed by a definite equation, but in order to illustrate the chemical principle involved, the simpler case of calcium fluoride, CaF_2, may be chosen. $CaF_2 + NaPO_3 + H_2O = CaNaPO_4 + 2HF$. It is evident that water or hydroxyl must be present in order to form HF, and this may come either from hydroxyl in the mineral or from a trace of water that was not wholly driven out from the sodium metaphosphate.

4. *Precipitation as Calcium Fluoride.*—This test is especially applicable for detecting small quantities of fluorine in silicates. The mineral is first fused with sodium carbonate, exactly as described under silicates (p. 110, § 4). The fusion is then pulverized, treated in a test-tube with 5 cc. of boiling water, filtered and washed, by which means sodium fluoride is obtained in solution. The filtrate is acidified with hydrochloric acid, boiled for a short time to expel carbon dioxide, a little calcium chloride added (some calcite dissolved in hydrochloric acid will answer), and then ammonia in excess. The precipitate will contain calcium fluoride, but a precipitate is *not a proof* that fluorine is present, for other compounds may be thrown down at this point. The precipitate must be collected on a filter-paper, washed well with water, and ignited in a crucible until the paper is completely destroyed, when the residue is tested according to § 2. It is not safe to test according to § 1, for sometimes considerable silica is precipitated with the calcium fluoride, and in that case the hydrofluoric acid will derive silica from the precipitate instead of etching the glass.

5. *Acid Water in a Closed Tube.*—Most minerals containing fluorine and hydroxyl yield acid water in the closed tube, which reddens blue litmus-paper, and when the reaction is strong the glass is distinctly etched. Unless the glass is etched, however,

a proof of the presence of fluorine must be obtained by testing according to some of the foregoing methods. In cases where fluorine is isomorphous with hydroxyl, hydrofluoric acid will sometimes be given off instead of water. The acid then etches the glass, forms a deposit of silica, and gives a strong pungent smell at the end of the tube. From Brazilian topaz, for example, which on analysis yields 2.5 per cent of water, the hydrogen is mostly expelled as hydrofluoric acid, and there is scarcely any indication of water, but, if freshly ignited lime or magnesia is mixed with the mineral in the closed tube, the fluorine will be retained and water driven off.

Gallium, Ga.—Trivalent. Atomic weight, 69.8.

OCCURRENCE.—This exceedingly rare metal has been found in traces in sphalerite from a few localities. It is best detected by means of the spark spectrum.

Germanium, Ge.—Tetravalent. Atomic weight, 72.3.

OCCURRENCE.—This very rare element has been found in argyrodite, Ag_6GeS_6; canfieldite, $Ag_8(SnGe)S_6$, in which tin and germanium are isomorphous, and in small quantity in the rare mineral euxenite.

DETECTION.—When argyrodite is heated before the blowpipe on charcoal, germanium volatilizes, and gives at first a pure white coating of oxide near the assay, which on prolonged heating moves farther out and assumes a greenish to brownish but mainly lemon-yellow color. When examined with a lens, the coating presents a glazed or enamel-like surface, while scattered about on the charcoal near the assay, fused, transparent to milk-white globules of germanium oxide may be detected.

In the closed tube, heated intensely before the blowpipe, a slight sublimate of germanium oxide forms, pale yellow when hot, becoming lighter on cooling, which with a lens may be seen to consist of numerous colorless to pale yellow globules.

Germanium gives no reaction in the open tube. It also imparts no characteristic color to the flame, to the fluxes, or to its solution in acids.

Glucinum, G.—See *Beryllium.*

Gold, Au.—Univalent and trivalent. Atomic weight, 197.3.

OCCURRENCE.—Gold occurs usually in the free state, that is, as *native gold*, which always contains some silver and sometimes traces of copper and iron. Native gold from California generally contains about 88 per cent of the pure metal. Gold is found disseminated in small quantity in the rocks of some regions, especially the crystalline schists. It is often concentrated in veins, where it is usually associated with quartz and pyrite, and it collects in the sands and gravels which have resulted from the disintegration of rocks and mountain masses that have contained gold. Owing to its weak chemical affinity it does not form very stable compounds, and the only element with which it is found in chemical combination in nature is tellurium. Petzite, sylvanite, krennerite, and calaverite are tellurides of gold and silver, and nagyagite is a telluride and sulphide of lead and gold.

DETECTION.—The color, fusibility, malleability, high specific gravity, and insolubility in any one acid are characters which serve for the ready detection of native gold.

As gold is worth $20.67 a troy ounce, only a small percentage of the metal is needed to make an ore very valuable. One per cent would be equal to 291.66 troy ounces a ton, worth $6028. An ore containing $\frac{1}{100}$ per cent of gold would be a rich one, and under favorable conditions, by hydraulic mining, gravels are washed which do not carry over ten cents worth of gold a ton, or less than $\frac{2}{1000000}$ of one per cent of the pure metal.

Washing and Collecting in Mercury.—When gold is present in very small quantity, even less than $\frac{1}{1000}$ of one per cent, it may be usually detected with great ease by washing or panning. This process consists in washing away with water the lighter rock constituents (for the most part less than 3 in specific gravity) from the gold, which varies from 15 to 19.3 in specific gravity, according to the proportion of silver it contains. In order to make the test, select a sample of the ore weighing at least a pound, pulverize it, and sift the material through a fine sieve. At the end of the operation, care must be taken to look for particles of gold on the sieve, for, being malleable, the particles are not pulverized. The powder, and the metal left on the sieve, if there is any, are put in a metal pan, $\frac{1}{2}$ cc. of mercury is added, and the pan is immersed in water and agitated for some time with a rocking and twisting motion, by which means the heavy gold goes rapidly to the bottom, while the lighter constituents arrange themselves above according to differences in specific gravity. From time to time the pan is inclined, and by a little motion a ripple of water is made to pass over the contents of the pan, and carry off some of the lighter material from the top. By continuing this process, the material is finally concentrated so that the gold is contained in a very small volume, and is taken up by the mercury at the bottom of the pan. To get rid of the last of the rock material, the contents of the pan are transferred to a mortar, and ground in a stream of water, by which treatment the fine particles are rapidly carried away, and finally only the mercury, with which the gold has amalgamated, is left. In order to obtain the gold, the mercury containing it is dried with blotting-paper, transferred to a shallow cavity on charcoal, and volatilized by heating with a small blowpipe flame. The residual gold may be fused to a globule, using a little borax or sodium carbonate when necessary. In order that no ill effects may result from the poisonous mercury vapors, a piece of wet blotting-paper should be placed on the charcoal, care being taken not to wet the cavity, and another piece arched over it (Fig. 48), thus furnishing a large cooling surface upon which the mercury will condense.

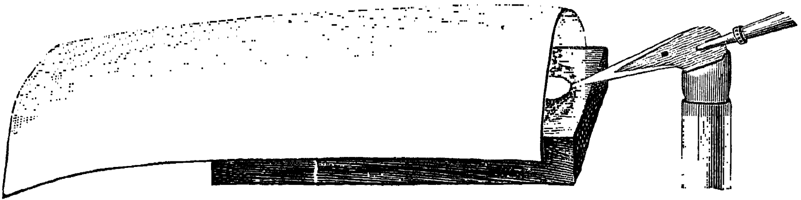


FIG 48.

When tellurides are to be tested, the powdered ore should be roasted and then washed as directed above. The roasting may be accomplished by putting the ore in an iron pan (a piece of sheet iron with the edges turned up) and heating it to faint redness in a stove for some time. It is well to stir the powder occasionally with an iron wire.

Gold may be washed or panned without the use of mercury. After washing away the lighter material the particles of gold may often be seen on the bottom of the pan as a "*color.*" The metallic particles may be collected in mercury and treated as directed in the foregoing paragraph, or the concentrated material may be fused with test lead and borax, and treated as directed under the silver assay,(p. 114, § 2).

The gold globules obtained by the foregoing processes will always contain some silver. In order to obtain the pure gold, the metal should be fused with about 3 times its weight of pure silver, and then treated in a porcelain dish or capsule with a little warm nitric acid, which dissolves the silver and leaves the gold as a brownish-black powder or dark coherent mass. This process of separating gold from silver is called *parting*. The finely divided gold may be washed and finally collected and fused into a globule on charcoal.

In exceptional cases, platinum or some of the metals of the platinum group may be found with the gold.

Helium, He.—Atomic weight, 4?.

OCCURRENCE.—This element has been recently discovered, and it seems to be present only in minerals containing uranium, thorium, and yttrium. It is given off as a gas when minerals containing it are heated or are dissolved in sulphuric acid. It is detected by means of the spark spectrum.

Hydrogen, H.—Univalent. Atomic weight, 1.

Occurrence.—Hydrogen is found abundantly in nature in combination with oxygen as *water*, and in combination with carbon in *hydrocarbons* (p. 61). There are many minerals which crystallize with a definite quantity of water, known as *water of crystallization.* This water constitutes a part of the chemical molecule, and is always expressed in the formula. Thus, gypsum is $CaSO_4.2H_2O$, and it contains 21 per cent of H_2O; natron is $Na_2CO_3.10H_2O$, and it contains 63 per cent of H_2O. Such minerals are called *hydrous*, while those containing no water are *anhydrous.* It is characteristic of water of crystallization that it is expelled from a mineral by very gentle ignition, always at a temperature far below a red heat and frequently below 100° C. Again, there are minerals containing the univalent radical *hydroxyl*, OH, which are known as *hydroxides.* For example brucite is magnesium hydroxide, $Mg(OH)_2$ or MgO_2H_2, and limonite is a ferric hydroxide, $Fe_4O_3(OH)_6$. Hydroxides when heated yield water. Thus, brucite, $Mg(OH)_2 = MgO + H_2O$, and limonite, $Fe_4O_3(OH)_6 = 2Fe_2O_3 + 3H_2O$, but it is characteristic for hydroxides that they must be *strongly heated*, sometimes to a white heat, before they are decomposed and water is given off. They thus differ from compounds containing water of crystallization.

Water of Crystallization and Hydroxyl.

Detection.—Water is readily detected by means of the closed-tube reaction.

1. *Closed-tube Reaction.*—Minerals containing either water of crystallization or hydroxyl, when heated in the closed tube, yield water, which collects on the cold walls of the tube. The test is very delicate, and usually pure distilled water is obtained which is neutral to test-papers.

a. To illustrate this reaction, heat gypsum or brucite in a closed tube, using fragments about 2 to 4 mm. in diameter, and also make one experiment with a minute fragment, in order to show the small quantity of water which may be detected by this means.

b. To illustrate the difference between water of crystallization and hydroxyl, take two closed tubes of equal size, place some gypsum in one and brucite in the other, and then, holding the tubes side by side, pass them back and forth through a small flame so as to heat the ends slowly and equally. In the tube containing gypsum, water is driven off when the temperature is scarcely above 100° C., while brucite does not yield water until the temperature is much higher.

2. *Acid Water in the Closed Tube.*—Hydrous compounds of the weak basic elements, such as iron, aluminium, copper, and zinc, with volatile acids, are decomposed on strong ignition, yielding acid water (compare the tests for Fluorine, p. 77, § 5, and for a sulphate, p. 123, § 3).

An excellent closed-tube experiment may be made with copperas, $FeSO_4 . 7H_2O$, which it is well to compare with that of gypsum. By heating very gently, only neutral water is driven off at first, but on stronger ignition the $FeSO_4$ is decomposed into FeO and SO_3. A secondary reaction also sets in, giving SO_2, which may be detected by its odor. $2FeO + SO_3 = Fe_2O_3 + SO_2$. Both SO_3 and SO_2, the anhydrides of sulphuric and sulphurous acids, render the water in the tube strongly acid. The strong basic elements, such as sodium, potassium, calcium, strontium, and barium, form *stable sulphates*; that is, sulphates which are not decomposed except by intense ignition, and which do not part with their acid constituents in a closed tube.

3. *Alkaline Water in the Closed Tube.*—Minerals which yield alkaline water are of rare occurrence, but it is sometimes obtained from those containing ammonia.

Indium, In.—Trivalent. Atomic weight, 113.3.

OCCURRENCE.—This exceedingly rare metal has been found in small quantity in sphalerite from a few localities. Its presence is revealed by the blue color it imparts to non-luminous flames, and these when examined with the spectroscope show an intense indigo-blue and a less intense violet line.

Iodine, I.—Univalent. Atomic weight, 127.

OCCURRENCE.—Iodine is rarely met with, and the only known minerals containing it are iodyrite, AgI; marshite, CuI; and lautarite, $Ca(IO_3)_2$.

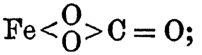
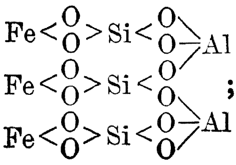
DETECTION.—The reactions of iodine are similar to those of chlorine and bromine (see p. 67). Silver nitrate precipitates silver iodide, AgI, which differs from silver chloride and silver bromide in being almost insoluble in ammonia. With potassium bisulphate in a bulb tube, either with or without pyrolusite, iodine is liberated, and may be recognized by its violet vapors, or, if the reaction is strong, by its crystallization in the tube. Silver iodide when heated in a closed tube with galena yields a sublimate of lead iodide, which is dark orange-red when hot, changing to lemon-yellow when cold.

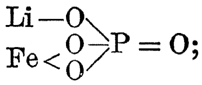
Iridium, Ir.—Trivalent and tetravalent. Atomic weight, 193.

Iridium is one of the rare metals occurring with platinum (see p. 104).

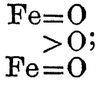
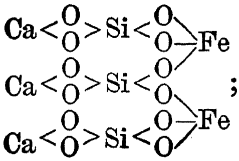
Iron, Fe.—Bivalent in ferrous and trivalent in ferric compounds. Atomic weight, 56.

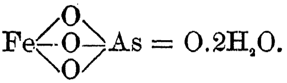
OCCURRENCE.—Iron is found very abundantly in minerals (p. 3), and those from which most of the metal of commerce is made are magnetite, Fe_3O_4; hematite, Fe_2O_3; limonite, $Fe_4O_3(OH)_6$; and siderite, $FeCO_3$. Iron is found in a great variety of combinations with sulphur (pyrite, FeS_2; pyrrhotite, $Fe_{11}S_{12}$; and chalcopyrite, $CuFeS_2$), and among the salts of most of the mineral acids, silicates, phosphates, etc. It is important to distinguish between two classes of compounds, the *ferrous* containing bivalent, and the *ferric* containing trivalent, iron. Examples of *ferrous* compounds are:

siderite, 
$\mathrm{Fe}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{C}=\mathrm{O}$; **almandine garnet,** 
$$\begin{matrix}\mathrm{Fe}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{Si}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{Al}\\ \mathrm{Fe}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{Si}<\genfrac{}{}{0pt}{}{O}{O}\\ \mathrm{Fe}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{Si}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{Al}\end{matrix}$$
; and

triphylite, 
$$\begin{matrix}\mathrm{Li}-\mathrm{O}\\ \mathrm{Fe}<\genfrac{}{}{0pt}{}{O}{O}\end{matrix}>\mathrm{P}=\mathrm{O};$$

and of *ferric* compounds:

hematite, 
$$\begin{matrix}\mathrm{Fe}=\mathrm{O}\\ \mathrm{Fe}=\mathrm{O}\end{matrix}>\mathrm{O};$$
andradite garnet, 
$$\begin{matrix}\mathrm{Ca}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{Si}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{Fe}\\ \mathrm{Ca}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{Si}<\genfrac{}{}{0pt}{}{O}{O}\\ \mathrm{Ca}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{Si}<\genfrac{}{}{0pt}{}{O}{O}>\mathrm{Fe}\end{matrix}$$
; and

scorodite, 
$$\mathrm{Fe}\begin{matrix}\diagup\mathrm{O}\diagdown\\ -\mathrm{O}-\\ \diagdown\mathrm{O}\diagup\end{matrix}\mathrm{As}=\mathrm{O}.2H_2O.$$

Many minerals contain both ferrous and ferric iron, as magnetite, $Fe_3O_4 = FeO + Fe_2O_3$. Ferrous iron is very often isomorphous with the bivalent metals, magnesium, manganese, zinc, cobalt, and nickel; and ferric iron, with the trivalent metal aluminium.

DETECTION.—The magnet will usually serve for the detection of iron, while more delicate tests can be made with the fluxes or in the wet way with potassium ferri- and ferrocyanides.

1. *Test with a Magnet.*—Only a few of the minerals containing iron (magnetite and pyrrhotite) are attracted by the ordinary magnet,* but many of them, especially the sulphides, oxides, and carbonates, become magnetic after being heated before the blowpipe in the reducing flame, either on charcoal or in the forceps. When thus heated, silicates and phosphates become magnetic only when they contain a rather large percentage of iron, but the test is rendered more delicate if the powdered mineral is fused on charcoal with about twice its volume of sodium carbonate, and the resulting slag tested with a magnet.

A magnet will not attract a piece of red-hot iron, and fragments of minerals that have been heated will not be attracted until they have become cold.

a. Illustrate the above by testing fragments of pyrite and hematite with a magnet, both before and after heating in the reducing flame (compare experiments *e* and *f* on p. 38).

b. Test almandine garnet with a magnet, after fusing before the blowpipe, and also test the slag made by fusing the powdered mineral with sodium carbonate on charcoal.

2. *Test with the Borax Bead.*—The oxides of iron are soluble in borax, and give colors which depend upon the amount of material in solution and the state of oxidation of the iron. In the oxidizing flame, the bead contains Fe_2O_3, and with little oxide it is yellow (amber-colored) when hot, fading to nearly colorless

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* An electromagnet, arranged with its poles close together so as to give a concentrated field, attracts all minerals containing iron, unless the percentage of the metal is small.

when cold, while with more oxide it is brownish-red when hot and yellow when cold. In the reducing flame, the bead contains FeO, or FeO with Fe_2O_3, and the colors are not so intense, with little oxide, being pale green when hot, colorless when cold; and with more oxide, bottle-green when hot, changing to a paler shade on cooling.

3. *Test with the Salt of Phosphorus Bead.*—In the oxidizing flame with little oxide, the color is yellow when hot, changing to colorless when cold, and with more oxide, brownish-red, changing through yellow to nearly colorless. In the reducing flame with little oxide, the color is pale yellow when hot, fading through pale green to colorless, and with more oxide, brownish-red when hot, changing on cooling to yellowish-green, and finally to nearly colorless or, if much oxide was used, to a *very pale* violet.

4. *Special Tests for Ferrous and Ferric Iron.*—With the exception of the sulphides and a few rare combinations, if minerals are dissolved in hydrochloric or sulphuric acid, the solution will contain the iron in the same state of oxidation as it existed in the original substance. For example, siderite, *ferrous* carbonate, and hematite, *ferric* oxide, when dissolved in hydrochloric acid, yield *ferrous* and *ferric* chlorides, respectively. $FeCO_3 + 2HCl = FeCl_2 + H_2O + CO_2$, and $Fe_2O_3 + 6HCl = 2FeCl_3 + 3H_2O$.

Ferrous Iron.—This may be detected by adding *potassium ferricyanide* to the cold, dilute, acid solution, when a deep blue precipitate of ferrous ferricyanide will be formed, which does not differ in color from Prussian blue. $3FeCl_2 + K_6Fe_2(CN)_{12} = Fe_3Fe_2(CN)_{12} + 6KCl$.

In solutions containing ferrous salts, potassium ferrocyanide produces a pale bluish-white precipitate of $K_2Fe_2(CN)_6$, which by absorption of oxygen from the air speedily acquires a blue color. Ammonium sulphocyanate causes no coloration in solutions of ferrous salts, provided they are entirely free from ferric compounds.

Ferric Iron.—This may be detected by adding *potassium ferrocyanide*, to the cold, dilute, acid solution, when a deep blue precipitate of ferric ferrocyanide, or Prussian blue, will be formed. $4FeCl_3 + 3K_4Fe(CN)_6 = Fe_4Fe_3(CN)_{18} + 12KCl$.

Addition of ammonium sulphocyanate, NH_4CNS, produces, even in dilute solutions of ferric salts, an intense blood-red color, but no precipitate.

Potassium ferricyanide deepens the color of solutions containing ferric salts, but fails to produce a precipitate.

Conversion of Iron from One State of Oxidation to the Other.—*a.* Ferrous iron may be converted to ferric by boiling the hydrochloric acid solution with a few drops of nitric acid. The reaction is a rather complicated one, but in principle it is simple. Nitric acid furnishes oxygen, and the change may be indicated as follows; $2FeCl_2 + 2HCl + O = 2FeCl_3 + H_2O$.

b. Ferric iron may be changed to ferrous by boiling the hydrochloric acid solution with metallic tin or zinc until the yellow color entirely disappears (see p. 26).

Prepare a solution containing ferrous iron by dissolving ½ ivory spoonful of powdered siderite in 5 cc. of boiling hydrochloric acid.

a. To illustrate the reaction for ferrous iron, take a few drops of the solution in a clean test-tube, dilute with cold water, and add a little of a freshly prepared solution of potassium ferricyanide, but avoid using a large excess of the reagent, for in this case, owing to the yellow color of the solution, the precipitate, when suspended in it, will appear green instead of blue.

b. To show the conversion of ferrous to ferric iron, boil the remainder of the solution with a few drops of nitric acid, and note the change in color.

c. To illustrate the reactions for ferric iron, take a few drops of the solution, oxidized as directed in the foregoing paragraph, dilute with water, and add a little potassium ferrocyanide, or test a similar dilute solution with ammonium sulphocyanate. Save the remainder of the solution for the experiment under § 5.

The tests with *potassium ferricyanide* for ferrous iron and with *potassium ferrocyanide* for ferric iron are exceedingly delicate, and a very good way of applying them is to take drops of each reagent on a clean porcelain plate, and by means of a glass rod or tube to bring in contact with them drops of the solution to be tested.

Detection of Ferrous and Ferric Iron in Insoluble Minerals, especially Silicates.—Most minerals which are insoluble in acids may be dissolved after they have been decomposed by fusion with borax. To make the test, take about ¼ ivory spoonful of the *finely powdered* mineral and three times its volume of powdered borax-glass in a rather large closed tube, and fuse in a Bunsen-burner flame. While hot, crack the glass about the fusion by touching drops of water to it, break off the end, transfer to a test-tube containing 3 cc. of hydrochloric acid and boil for about a minute, then dilute with 5 cc. of water. Divide the solution into two parts and test one for ferrous iron with potassium ferricyanide, the other for ferric iron either with ammonium sulphocyanate or potassium ferrocyanide. The tests are very decisive, and oxidation resulting from contact with the air and reduction during fusion, which can not be wholly avoided, are so trifling that practically they may be disregarded.

5. *Precipitation of Ferric Iron with Ammonia.*—Ammonia added in excess to a solution containing ferric iron precipitates the latter completely as brownish-red ferric hydroxide. $FeCl_3 + 3NH_4OH = Fe(OH)_3 + 3NH_4Cl$. The precipitate can be readily filtered, and thus iron can be wholly removed from a solution. Ferrous iron is partially thrown down by ammonia as a dirty green precipitate, which slowly acquires a brown color, owing to the absorption of oxygen from the air.

Lanthanum, La.—Trivalent. Atomic weight, 138.

The reactions of this rare earth-metal are given under Cerium.

Lead, Pb.—Bivalent and tetravalent. Atomic weight, 207.

Occurrence.—Lead is very widely distributed in nature and is found most abundantly in galena, PbS. Among various other combinations, the commonest are cerussite, $PbCO_3$; anglesite, $PbSO_4$; pyromorphite, $Pb_4(PbCl)(PO_4)_3$; and wulfenite, $PbMoO_4$. It is worthy of note that silicates of lead are exceedingly rare.

Detection.—The formation of metallic globules and a coating of the oxide on charcoal are usually sufficient for the detection of lead.

1. *Reduction on Charcoal to Metallic Lead and Formation of a Coating of Lead Oxide.*—Lead is readily reduced from its

compounds, and one of the best methods for its detection is to mix ¼ ivory spoonful of the powdered mineral with an equal volume of charcoal-dust and about 3 volumes of sodium carbonate, moisten to a paste with water, transfer to a flat charcoal surface or a shallow cavity, and heat before the blowpipe in a moderately strong reducing flame. By a little manipulation of the blast, the particles of lead may be made to move about and unite into a single globule, which appears bright when covered with the reducing flame, but on cooling becomes dull, owing to a coating of oxide. Lead is, moreover, somewhat volatile, and that portion which passes off as vapor unites with the oxygen of the air, and deposits on the charcoal as a coating of oxide, which is sulphur-yellow near, and bluish-white distant from the assay. The coating is volatile when heated in either the oxidizing or reducing flame. The lead globule is soft and malleable, and may be cut with a knife or flattened by hammering on an anvil.

The test may be made with cerussite or other lead compound, and it will be well to make a good-sized lead globule for use in future experiments. The best idea of the coating of lead oxide may be obtained by removing the globule to a shallow cavity in a fresh piece of charcoal, and heating for a short time before the blowpipe at the tip of the blue cone.

From the foregoing reaction on charcoal, the identity of lead is seldom doubtful, but the test is sometimes modified by the presence of other elements, while bismuth gives reactions which in appearance are very similar to those of lead.

When galena is roasted alone on charcoal at a rather high temperature, an abundant white sublimate is formed, resembling oxide of antimony, and consisting chiefly of some volatile combination of PbO and SO_2. If roasted carefully, however (p. 39, Fig. 41), at a very low temperature, SO_2 is given off, and a globule of lead formed, accompanied by the yellow coating of lead oxide, but without much of the white coating just mentioned.

In the presence of sulphide of antimony, it is recommended to roast the powdered mineral on charcoal with a very small oxidizing flame, until the antimony is mostly volatilized, and then to add sodium carbonate to the residue, and heat in the reducing flame so as to form globules of metallic lead, which, however, will still contain some antimony.

2. *Iodine Test.*—When a coating of lead oxide on charcoal is moistened with a few drops of hydriodic acid and heated with a small flame, a volatile and very conspicuous chrome-yellow deposit of lead iodide is formed, which appears greenish-yellow when there is only a thin coating of it on the coal. A similar coating may be obtained by adding to the powdered mineral from 2 to 4 volumes of a mixture of potassium iodide and sulphur (p. 26), and heating on charcoal in a small oxidizing flame, or by heating on a gypsum tablet as described on p. 17.

3. *Flame Coloration.*—Lead compounds, when heated in a reducing flame before the blowpipe, may impart a pale azure-blue color to the flame, showing a greenish tinge in the outer parts. If the experiment is made in the forceps, special care must be taken not to alloy the platinum.

4. *Solution and Precipitation of Lead.*—It is best to use dilute nitric acid (1 part HNO_3 to 2 of water) for the solution of lead minerals. Concentrated nitric acid will not answer, owing to the insolubility of lead nitrate in it. From solutions containing lead, sulphuric and hydrochloric acids throw down lead sulphate, $PbSO_4$, and lead chloride, $PbCl_2$, respectively, as heavy white precipitates. The chloride is quite soluble in hot water and sparingly so in cold, therefore it will not be formed in solutions which are hot or too dilute. It is frequently convenient to dissolve a lead mineral in rather dilute boiling hydrochloric acid, when, on cooling, most of the lead will crystallize out as lead chloride.

Tests may be made by dissolving the lead globule from § 1 in about 3 cc. of dilute nitric acid, dividing into 2 parts, and adding to one a few drops of dilute sulphuric and to the other a few drops of hydrochloric acid. They may also be made with the solution obtained by dissolving some lead mineral (cerussite or pyromorphite) in dilute nitric acid.

In some minerals, it may be found advantageous to test for lead as follows: Decompose from 3 to 5 ivory spoonfuls of the fine powder in a casserole with nitric acid, add 2 cc. of concentrated sulphuric acid, and evaporate until the nitric acid is removed, and white, choking fumes of sulphuric acid commence to come off. When the dish becomes cold, add water, stir for some time, then filter off the insoluble lead sulphate, and test some of it according to § 1.

Lithium, Li.—Univalent. Atomic weight, 7.

OCCURRENCE.—This alkali metal is found only in the silicates and phosphates, but is not of very rare occurrence. The commonest minerals containing it are lepidolite, $LiK[Al(F.OH)_2]Al(SiO_3)_3$; spodumene, $LiAl(SiO_3)_2$; triphylite, $LiFePO_4$; lithiophilite, $LiMnPO_4$; amblygonite, $Li[Al(F.OH)]PO_4$; and some varieties of tourmaline and mica.

DETECTION.—The crimson color which lithium imparts to a flame will usually serve for its detection. The test may be made according to directions given on p. 35. The color of a pure lithium flame is nearly monochromatic, showing, when examined with the spectroscope, one bright crimson and one very faint yellowish-red band. In testing minerals, it will be found that the appearance of the flame is somewhat modified by the presence of other substances, especially sodium, which is apt to occur in small quantities with lithium, but usually its disturbing influence may be overcome by the fact that lithium is more volatile than sodium. When, therefore, the assay is first introduced into the flame, the red of lithium will show before the yellow of sodium, and when the flame is strongest, if the position of the assay is changed to where the heat is less intense, the yellow will disappear first, and finally the red of lithium will be distinctly seen. Where the proportion of sodium is large, however, the spectroscope must be resorted to. In testing silicates, it will often be found advantageous to mix the assay with powdered gypsum, and to heat as directed under potassium (p. 105, § 1, *c*). Colored glasses do not assist very much in the analysis of mixed flames containing lithium.

The crimson flame of lithium must not be mistaken for that of strontium, which it resembles very closely (p. 116, § 1).

Magnesium, Mg.—Bivalent. Atomic weight, 24.

OCCURRENCE.—Magnesium is a very common element (p. 3), being found in a great many silicates, several of which are important rock-making minerals; as pyroxene, amphibole, biotite, enstatite, olivine, and serpentine. It occurs also in a variety of other combinations, such as brucite, MgO_2H_2; magnesite, $MgCO_3$; dolomite, $MgCa(CO_3)_2$; spinel, $MgAl_2O_4$, etc. In the majority of its compounds, some ferrous iron is isomorphous with the magnesium.

DETECTION.—There are no satisfactory blowpipe tests for magnesium, and it is best detected in the wet way by precipitation as ammonium magnesium phosphate.

1. *Precipitation as Ammonium Magnesium Phosphate.*—From a solution made strongly alkaline with ammonia, *sodium phosphate* causes the formation of a white crystalline precipitate of ammonium magnesium phosphate, $NH_4MgPO_4.6H_2O$. Before making the test for magnesium, however, it must be ascertained that substances precipitated by ammonia, ammonium sulphide and ammonium carbonate or oxalate, have been removed from the solution, as otherwise a phosphate of some other element might be thrown down and mistaken for magnesium; while magnesium will not be precipitated by the above-mentioned reagents, provided (*a*) that the solution is sufficiently dilute, (*b*) that it contains some free mineral acid, such as hydrochloric or nitric, and (*c*) that it does not contain an acid with which magnesium forms an insoluble combination (phosphoric, for example). The manner in which the test is applied may be illustrated by the following experiments:

a. Dissolve ¼ ivory spoonful of brucite, MgO_2H_2, in 3 cc. of hydrochloric acid, warm if necessary, dilute with from 5 to 10 cc. of water, add ammonia in excess, and finally a few drops of a solution of sodium phosphate.

b. Dissolve ½ ivory spoonful of dolomite, $CaMg(CO_3)_2$ (with probably a trace of $FeCO_3$), in 3 cc. of boiling hydrochloric acid, add a drop of nitric acid to oxidize the iron, then 5 cc. of water, heat to boiling, add ammonia in excess, and filter, provided a precipitate of ferric hydroxide has formed (p. 87, § 5). To the filtrate containing calcium and magnesium chlorides add ammonium carbonate or oxalate, which precipitate calcium (p. 60, §§ 5 and 6), filter, and test the filtrate with sodium phosphate.

For the detection of magnesium in silicates and complex bodies, see p. 110, § 4.

2. *Alkaline Reaction.*—A few magnesium minerals become alkaline after ignition, but the test, which is made by placing the ignited material upon moistened turmeric-paper, is not very decisive nor satisfactory.

3. *Test with Cobalt Nitrate.*—Some of the white or colorless magnesium compounds, when moistened with cobalt nitrate and ignited before the blowpipe, assume a faint pink color, but the test is neither very general in its application nor very satisfactory.

Manganese, Mn.—In minerals, usually bivalent, but sometimes trivalent and tetravalent. Atomic weight, 55.

OCCURRENCE.—Manganese is very widely distributed in nature, small quantities of it, usually a fraction of 1 per cent, being found in many minerals and in most of the silicate rocks. Some of the common manganese minerals are pyrolusite, MnO_2; manganite, $MnO(OH)$; braunite, Mn_2O_3; hausmannite, Mn_3O_4; rhodochrosite, $MnCO_3$; rhodonite, $MnSiO_3$; tephroite, Mn_2SiO_4; and lithiophilite, $LiMnPO_4$. It occurs rarely as sulphide (alabandite, MnS, and hauerite, MnS_2).

DETECTION.—Manganese can be readily detected by means of the sodium carbonate and borax beads.

1. *Test with a Sodium Carbonate Bead.*—Oxide of manganese dissolves in a sodium carbonate bead, when heated before the blowpipe in the oxidizing flame, with the formation of sodium manganate, Na_2MnO_4. The bead thus formed is green when hot and bluish-green when cold. The test is a very delicate one, and other substances are not apt to interfere with it. In the reducing flame, the manganese is reduced to MnO and the bead loses its color.

The experiment can be made by dissolving a very little pyrolusite, or other mineral containing manganese, in a sodium carbonate bead made according to directions given on p. 24.

A similar test may be made by fusing some of the finely powdered mineral on platinum-foil or in a spoon with sodium carbonate, to which a little potassium nitrate has been added in order to bring about the oxidation. By this means a very small quantity of oxide of manganese, 0.10 per cent, may be detected by the bluish-green color of the fusion.

2. *Test with a Borax Bead.*—Oxide of manganese dissolves in borax, giving in the *oxidizing flame* a bead which is opaque while hot, but on cooling becomes transparent and has a fine reddish-violet or amethystine color, due to the presence of a higher oxide of manganese. It takes only a very little manganese to give this test, and if too much is added, the color of the bead is so intense that it appears black. If the bead is not too strongly colored, it will speedily become transparent while held in the reducing flame The manganese is thus reduced to a lower oxide, MnO, and the bead is colorless. If the bead containing MnO is again heated in the oxidizing flame, clouds, which indicate the presence of a higher oxide of manganese, soon make their appearance, and, on cooling, the bead is reddish-violet. Other substances which give colors to borax may, of course, interfere with this test.

3. *The Salt of Phosphorus Bead.*—This assumes an amethystine color with manganese if heated in the oxidizing flame, but the test is not so delicate nor satisfactory as with borax.

4. *The Higher Oxides of Manganese.*—There are a number of these containing more oxygen than MnO. They dissolve in hydrochloric acid with evolution of chlorine gas, and some of them, when heated, give oxygen gas (compare Oxygen, p. 100, §§ 1 and 2).

Mercury, Hg.—Bivalent in mercuric, and univalent in mercurous, compounds. Atomic weight, 200.

OCCURRENCE.—Mercury is not widely disseminated in nature and is found in only a few minerals, the one which furnishes most of the metal of commerce being cinnabar, HgS. The following are all of rather rare occurrence: native mercury; amalgam, Ag with Hg; tiemannite, HgSe; onofrite, HgSe with HgS; calomel, HgCl, and the varieties of tetrahedrite containing mercury.

DETECTION.—The formation of metallic mercury, by heating with sodium carbonate in a closed tube, is usually the most satisfactory test.

1. *Closed-tube Tests.*—If the pulverized mineral is intimately mixed with about 4 volumes of *dry* sodium carbonate, transferred to a closed tube, covered with an additional layer of sodium carbonate about ½ cm. long, and heated in a Bunsen-burner flame, at first rather cautiously, the mineral will be decomposed and metallic mercury will distil off and condense as globules on the walls of the tube. If only a little mercury is formed, it will appear as a gray sublimate composed of minute globules which may be made to unite by rubbing with a platinum wire or slip of paper.

Mercury compounds, when heated alone in a closed tube, usually volatilize without decomposition.

a. To make the test, take about ½ ivory spoonful of cinnabar and 2 of *dry sodium carbonate*, mix them intimately by trituration in an agate mortar, and proceed as directed above. Dry sodium carbonate may be had by heating some of the ordinary material below redness either in a porcelain crucible or on any clean metal surface. The reaction is as follows: $HgS + Na_2CO_3 = Hg + O + CO_2 + Na_2S$. On breaking the tube and placing some of the residue containing Na_2S on silver along with a drop of water, a test for the sulphur may be obtained (p. 120, § 5).

b. Heat some cinnabar alone in a closed tube, and observe the black sublimate of HgS, which resembles the arsenical mirror. Also observe that no metallic mercury is formed.

2. *Open-tube Reaction.*—A convenient way of testing sulphide of mercury is to roast a little of the mineral in a rather large open tube, when the products formed are essentially metallic mercury and SO_2. For success in this experiment, the tube is at first heated very hot just above the substance, and then the latter is heated *very carefully and gradually* so as not to drive off any black, unoxidized sublimate of HgS. Often a slight non-metallic sublimate forms, possibly some combination of oxide of mercury

and SO_2, but if this is driven up the tube by heat, it is for the most part decomposed, and the resulting gray sublimate will be found to consist of minute globules of mercury, which may be united by rubbing with a wire or slip of paper.

3. *Precipitation upon Copper.*—If a bit of clean copper is placed in a solution containing mercury, the mercury will deposit in the metallic state upon the copper, and the latter will then appear as if it had been silver-plated.

Boil a mixture of powdered cinnabar and pyrolusite for a short time with hydrochloric acid, dilute with water, and introduce into the cold solution a copper coin or strip previously cleaned by dipping it into strong nitric acid and washing with water. The action of the pyrolusite is to liberate chlorine (p. 101, § 2), which is essential for the solution of the cinnabar. The deposition of mercury upon the copper is due to a simple interchange of the metals. $HgCl_2 + Cu = Hg + CuCl_2$.

Molybdenum, Mo. — Tetravalent and sexivalent. Atomic weight, 96.

Occurrence.—Molybdenum is found sparingly in nature, and mostly as molybdenite, MoS_2, and wulfenite, $PbMoO_4$.

Detection.—The character of the test for molybdenum depends upon whether the element occurs as sulphide or in an oxidized condition. For the former, an oxidation, and for the latter, a reduction test is recommended.

1. *Roasting on Charcoal.*—If a fragment of molybdenite is heated on a flat charcoal surface for a considerable time in the oxidizing flame, there results, at a short distance from the assay, a coating of molybdic oxide, MoO_3. This is pale yellow when hot, almost white when cold, and often consists of delicate crystals. Still nearer to the assay, the charcoal is covered with a very thin, tarnished, copper-colored coating of MoO_2, which is seen best when cold and by reflected light. The MoO_3 coating is volatile in the oxidizing flame, and, if touched for an instant with a moderately hot reducing flame, it assumes a beautiful ultramarine-blue color (very characteristic), due probably to a combination of MoO_2 and MoO_3.

2. *Roasting in the Open Tube.*—If thin shavings of molybdenite are heated at a high temperature in an open tube, a yellow sublimate of MoO_3 deposits a little above the assay, and frequently forms a mass of delicate crystals.

3. *Flame Test.*—A fragment of molybdenite, held in the forceps and heated before the blowpipe at the tip of the blue cone, imparts a pale yellowish-green color to the flame.

4. *Reduction Test.*—In a test-tube take about ⅓ ivory spoonful of finely powdered molybdate (wulfenite, $PbMoO_4$) and a scrap of paper not over 1 mm. square, add from 3 to 6 drops of water and an equal quantity of concentrated sulphuric acid and heat until copious fumes of the acid begin to come off, then, after allowing the tube to become cold, add water a drop at a time. The addition of the first few drops of water gives rise to a magnificent deep-blue color, which quickly disappears when the quantity of water added amounts to a few cubic centimeters. The exact nature of this reaction is not well understood, but it is due presumably to a slight reducing action caused by the presence of the paper. It generally does not succeed well when only a very minute quantity of mineral is tested.

5. *Reactions with the Fluxes.*—The salt of phosphorus bead is best. If a small quantity of the oxide is dissolved in the bead in the oxidizing flame, the glass is yellowish-green when hot, changing to almost colorless when cold. In the reducing flame it becomes dirty green when hot, changing to a fine green on cooling. The tests with borax are neither very satisfactory nor decisive.

Nickel, Ni.—Bivalent. Atomic weight, 59.

OCCURRENCE.—Nickel is a comparatively rare element, occurring most often as a sulphide or arsenide, and associated usually with cobalt and iron. Some of its important compounds are millerite, NiS; niccolite, NiAs; chloanthite, $NiAs_2$; gersdorfite, NiSAs; penthandite, NiS with FeS; and genthite, a hydrous silicate of nickel and magnesium. Nickel is found with cobalt in most of the sulphides and arsenides mentioned under the latter element, and much of the metal of commerce is obtained from nickeliferous pyrrhotite, essentially FeS, but containing from 1 to 5 per cent of Ni isomorphous with the Fe.

DETECTION.—The element is usually detected by the color its oxide imparts to the borax bead in the oxidizing flame.

1. *Test with a Borax Bead.*—Oxide of nickel dissolves in the borax bead, and in the oxidizing flame yields a violet color when hot, not unlike the color given by manganese, but changing to reddish-brown on cooling. By rather long heating in a strong reducing flame, the bead becomes opaque, owing to the separation of metallic nickel, and if the bead is removed from the wire and fused on charcoal in the reducing flame together with a granule of

metallic tin, an alloy of tin and nickel is formed, and the glass finally becomes colorless or nearly so. A small percentage of cobalt will completely obscure the color of nickel, while a trace of cobalt in the presence of much nickel may be detected, as described on p. 71, § 1.

2. *Test with a Salt of Phosphorus Bead.*—This test for nickel is not very satisfactory. In the oxidizing flame, with little oxide, the bead is reddish when hot, and becomes pale yellow on cooling, while with much oxide it is brownish-red when hot, becoming reddish-yellow on cooling. In the reducing flame on platinum wire, the color of the bead is unchanged, but if heated for a long time on charcoal with a granule of tin, metallic nickel is formed, which alloys with the tin, and the glass becomes colorless.

3. *Test with Ammonia.*—This reagent, when added to a solution containing nickel, may cause a slight precipitate at first, but the precipitate speedily dissolves and imparts a pale blue color to the solution, which must not be confounded with the much deeper color given by copper when its solutions are treated in a similar way.

4. *Special Tests for Nickel and Cobalt when they Occur with Other Substances.*—Treat some of the powdered mineral in a casserole with acid (nitric is best if the mineral is a sulphide or arsenide), and boil until solution is effected and only about 5 cc. of acid remain. Then dilute with water, boil, add ammonia in considerable excess, and filter, when the nickel and cobalt, or at least the greater part of them, will be found in the filtrate free from iron. Boil the filtrate in a casserole, add caustic potash, and continue the boiling until the ammonia salts are decomposed, and addition of more potash does not produce any additional smell of ammonia. By this treatment, nickel and cobalt are precipitated as hydroxides. These should be collected on a filter and washed once or twice with hot water. Test some of the precipitate with a borax bead in the oxidizing flame, and if it shows the color of nickel, cobalt is absent, or present only in very small quantity (compare p. 71, § 1). If, on the other hand, the bead is blue, indicating cobalt, nickel is possibly present, and may be tested for as follows:

Ignite the paper with the precipitate in a porcelain crucible until the carbon is burned away, or, if there is a large quantity of the precipitate, some of it may be placed on charcoal and dried out with a blowpipe flame.

The dried material is then ground in a mortar with about twice its volume of metallic arsenic and a very little fused borax, transferred to a closed tube, and heated gently at first, and finally intensely, before the blowpipe, until the nickel and cobalt, which have now united with the arsenic to form arsenides, fuse into a single globule. The glass is then cracked, and the metallic globule freed as completely as possible from slag. It is next placed upon charcoal together with a bit of borax glass, and heated at first in the reducing flame and then continuously in the oxidizing flame, by which treatment the cobalt is slowly oxidized and imparts to the borax its characteristic color. Sometimes the color is not seen distinctly until some of the fused borax is taken up in the forceps and drawn out into a thread. If the quantity of cobalt is considerable, it may be necessary to remove the globule from the slag (best done by taking the globule in the forceps and plunging it while hot into cold water), and fuse it with a fresh portion of borax. As long as cobalt is present, nickel will not oxidize, and the surface of the bead remains bright while hot, but when the cobalt has all been removed, the nickel commences to oxidize, and its oxide forms a crust over the surface of the bead, which is not as readily dissolved by the borax as the oxide of cobalt. The appearance of the bead, therefore, indicates that cobalt is no longer present, and if the bead is removed and fused against a fresh portion of borax, it imparts to the latter the brown color characteristic for nickel. Considerable experience in the use of the blowpipe is needed to carry out this operation successfully. Sometimes a mineral may be fused directly in the reducing flame, to a globule of sulphide or arsenide, and then treated in the oxidizing flame with borax on charcoal as described above. If iron is present, it oxidizes before the cobalt. Copper, which does not interfere with the test, oxidizes only after the nickel has all been removed.

For the detection of small quantities of nickel in pyrrhotite, the test as given above may be recommended.

Niobium, Nb.—Pentavalent. Atomic weight, 94.

OCCURRENCE.—Niobium, called also *columbium, Cb,* is almost invariably associated with tantalum, and together they constitute the acid-forming elements of a group of minerals known as the niobates and tantalates. The two elements are isomorphous with one another, and their compounds are characterized by being unusually heavy. Some of the more common minerals containing them are columbite, tantalite, pyrochlore, microlite, fergusonite, samarskite, euxenite, and polycrase. Niobium is, moreover, occasionally found in silicates, as wöhlerite.

DETECTION.—Niobium is best detected by boiling an acid solution containing it with metallic tin, and obtaining a blue color which is due to reduction.

1. *Reduction Test.*—As the niobates are usually very insoluble in acids, they must first be decomposed, which may be accomplished most conveniently as follows: Mix the finely powdered mineral with about 5 times its bulk of borax, moisten to a paste with water, take up some of the mixture in a loop on platinum wire, and fuse at a high temperature before the blowpipe. Make two or three of these beads, remove them from the wire, crush in a diamond mortar, and boil the powder with 5 cc. of hydrochloric acid, which should yield a clear or nearly clear solution. On adding some granulated tin, and boiling, the blue color of niobium will appear, which is not readily changed to brown by continued boiling, and which rapidly disappears upon addition of water. The blue color is due to reduction, but the composition of the compound which causes it is not definitely known. If titanium is present, the violet color due to the reduction of that element appears before the blue of niobium. An acid solution containing niobium, if treated in a similar manner with metallic zinc, becomes sometimes momentarily blue, but the color soon changes to brown, owing to reduction to $NbCl_3$. Tungsten gives similar reduction tests, but may be readily distinguished from niobium by a number of reactions mentioned under that element.

2. *Decomposition with Potassium Bisulphate.*—A method that is very generally adopted for the decomposition of niobates and tantalates is to fuse the finely powdered mineral with from 8 to 10 parts of potassium bisulphate. The fusion is ordinarily done in a crucible, but it may also be made in a test-tube, since the heat which is required need not exceed faint redness and the glass is not attacked. When the decomposition is complete, as shown by the disappearance of dark particles, the tube may be inclined and turned while cooling, causing the fusion to solidify as a thin crust on its sides, so that it may be more readily dissolved on subsequent treatment. It is digested with cold water, which requires considerable time (the application of heat is not recommended), and there is left an insoluble white residue consisting of niobic and tantalic oxides, while the bases are in solution. The insoluble oxides are collected on a filter and washed, and if a portion of them is treated in a test-tube with hot concentrated hydrochloric acid, and boiled with granulated tin, the blue color due to niobium may be obtained.

For the separation of small quantities of tungsten and tin from the insoluble niobic and tantalic oxides, see p. 126, § 3.

3. Oxide of niobium gives no satisfactory reactions with the fluxes.

Nitrogen, N.—Trivalent and pentavalent. Atomic weight, 14.

OCCURRENCE.—Nitrogen is the characteristic non-metallic element of nitric acid, HNO_3, and of the nitrates. The simple nitrates of the metals are soluble in water, and are not found as minerals in regions where there is a considerable rainfall. In arid regions, however, they may accumulate and be of great commercial importance, as the sodium nitrate deposits of Chili and Peru. The ammonium compounds also contain nitrogen, and have already been mentioned on p. 43.

DETECTION OF NITRATES.—When heated in a closed tube, or, better, in a bulb tube, with potassium bisulphate, nitrates are decomposed and yield NO_2 gas, which may be detected by its red color (seen best by looking into the tube lengthwise), and also by its odor. Potassium bisulphate may be omitted in testing nitrates of the heavy metals, for they are so readily decomposed that NO_2 gas is given off even on moderate ignition.

Osmium, Os.—See the platinum metals, p. 104.

Oxygen, O.—Bivalent. Atomic weight, 16.

OCCURRENCE.—Oxygen is the most abundant element in the crust of the earth (p. 3). With the exception of the native elements, the sulphides, fluorides, and halogen salts, oxygen is present in all minerals. Many elements unite with oxygen in varying proportions; those containing the smallest quantity of oxygen are called lower oxides, or *ous* compounds (FeO = *ferrous* oxide), and those with more oxygen, higher oxides, or *ic* compounds (Fe_2O_3 = *ferric* oxide).

DETECTION.—Usually no direct test is made for oxygen, but if a mineral is determined to be a salt of some oxygen acid, as carbonic or silicic, which may be readily done, it *must* contain oxygen; while, on the other hand, if it is a sulphide or chloride, it probably will not contain oxygen. However, oxysulphides, oxychlorides, and oxyfluorides, although rare, are known, as are also chlorides and fluorides containing water of crystallization. For some of the higher oxides, the closed-tube test, or the liberation of chlorine when dissolved in hydrochloric acid, may be applied.

1. *Closed-tube Reaction.*—Some of the higher oxides, when heated in a closed tube, yield oxygen gas, which is colorless and

odorless, but may be detected by burning a piece of charcoal in the tube.

Place some fragments of pyrolusite, MnO_2, in the bottom of a closed tube, and a little above, a sliver of charcoal (compare Fig. 45, p. 62); then heat the charcoal alone, and observe that although it gets red hot, it does not burn, owing to the limited supply of air in the tube. Keeping the charcoal hot, apply heat to the pyrolusite, and as soon as oxygen commences to be given off, the charcoal will burn brightly, and continue to do so as long as oxygen is supplied by the mineral. The reaction is $3MnO_2 = Mn_3O_4 + 2O$.

2. *Liberation of Chlorine.*—When some of the higher oxides are dissolved in hydrochloric acid, chlorine gas is liberated, which may be recognized by its peculiar odor and bleaching action, while ordinary oxides when similarly treated do not set chlorine free. These differences are illustrated by the following equations:

$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + 2Cl.$$

$$Fe_2O_3 + 6HCl = 2FeCl_3 + 3H_2O.$$

Whether chlorine is liberated or not depends upon the character of the metal. The oxygen of the oxide and hydrogen of the acid unite to form water, and if the chlorine thus available is more than sufficient to satisfy the valence of the metal, the excess will be liberated.

Treat one ivory spoonful of finely powdered pyrolusite, MnO_2, in a test-tube with 5 cc. of hot hydrochloric acid. Observe the odor of the escaping gas, and also bleach a piece of *moistened* litmus-paper by holding it for a short time within the test-tube.

Palladium, Pd.—See the platinum metals, p. 104.

Phosphorus, P.—Pentavalent (usually). Atomic weight, 31.

OCCURRENCE.—Phosphorus is the characteristic non-metallic element of phosphoric acid, H_3PO_4, and its salts, the phosphates. Although a great many phosphates are known, the majority of them are rare minerals, and many of them are isomorphous with arsenates and vanadates. The following will serve as illustrations:

apatite, $Ca_4(CaF)(PO_4)_3$; triphylite, $Li(Fe,Mn)PO_4$; and vivianite, $Fe_3(PO_4)_2.8H_2O$.

DETECTION.—Ammonium molybdate is the best reagent for the detection of phosphates, but the flame coloration or the reduction test with magnesium may be used.

1. *Test with Ammonium Molybdate.*—When a nitric acid solution of a phosphate is added to a solution of ammonium molybdate, according to the directions given beyond, a yellow precipitate of *ammonium phosphomolybdate*, approximately $Mo_{10}(NH_4)_2PO_{34}.1\frac{1}{2}H_2O$, is thrown down, and furnishes an exceedingly delicate test. Only a little of the phosphate solution should be added to the ammonium molybdate at first, since the precipitate may not form if an excess of phosphoric acid is present. The precipitation should take place in a cold or only slightly warmed solution, for if heated to boiling, other things, especially a corresponding arsenic compound might be thrown down and mistaken for the phosphate precipitate. If the mineral is insoluble in nitric acid, it may be first fused in a sodium carbonate bead and then dissolved in this acid. An acid other than nitric may be used for dissolving the mineral, but in that case it is best to nearly neutralize the excess of free acid with ammonia, before adding the solution to the ammonium molybdate. When applying this test, it is recommended to follow quite closely the details of the experiment as given below.

Dissolve $\frac{1}{4}$ ivory spoonful of apatite in about 3 cc. of warm nitric acid, and pour a few drops of the solution into another test-tube containing about 5 cc. of ammonium molybdate, when, after standing a few minutes in the cold, the yellow precipitate will make its appearance.

2. *Flame Test.*—Many phosphates when heated before the blowpipe impart a pale bluish-green color to the flame, while others often show the reaction if moistened with concentrated sulphuric acid and then heated. The color, although not very marked, is often sufficient for the identification of a phosphate (compare p. 136).

The experiment may be made with fragments of wavellite, $Al_6P_4O_{19}.12H_2O$, or apatite. In case the latter mineral is used, it is necessary to moisten the fragment with sulphuric acid, and then the color is distinct for only a short time.

3. *Reduction with Metallic Magnesium.*—Phosphates of the alkalies and alkaline earths, when strongly ignited in a closed tube with magnesium, are reduced, with the formation of a phosphide. This, when moistened with water, gives the disagreeable odor of phosphuretted hydrogen, PH_3, somewhat like the garlic odor of arsenic. When phosphates of aluminium and the heavy metals are to be tested, it is best to fuse the powdered mineral with 2 parts of sodium carbonate on charcoal, to remove and grind up the fused mass, and then to ignite the powder with magnesium.

The experiment may be made with apatite or wavellite. In the latter case, however, the mineral should first be fused with sodium carbonate.

Take a piece of magnesium ribbon about 25 mm. long, roll or fold it up into a compact mass, and drop it into a closed glass tube. Next add the finely powdered phosphate, tap the tube so as to bring the powder as much as possible in contact with the magnesium, and ignite very strongly with a blowpipe flame, being careful to hold the tube in such a manner that, if an explosion should occur, the contents would not be shot out into the face. Crack off the end of the tube by dropping water upon it while it is still hot, moisten the contents with a few drops of water, and observe the odor of the phosphuretted hydrogen; or, after allowing the tube to become cold, introduce a drop or two of water, and observe the odor at the end of the tube.

Platinum, Pt.—Bivalent and tetravalent. Atomic weight, 195.

Occurrence.—Platinum is found native, but it then always contains some iron and traces of other metals belonging to the platinum group. The only mineral containing platinum in chemical combination is sperrylite, $PtAs_2$.

Detection.—The color, high specific gravity, infusibility, and insolubility in any single acid, are properties which serve for the identification of platinum. When the metal occurs in sand, it may be concentrated by washing as described under gold, but without using mercury. For a more definite test for platinum, it is recommended to fuse the metal in a cavity on charcoal with some test-lead, using borax, if necessary, to take up impurities. The metallic globule, freed from slag by hammering, is then treated with dilute nitric acid ($1HNO_3 : 2H_2O$), which dissolves everything but the platinum metals and gold, and these are then collected upon a filter-paper, washed, and ignited. The finely divided platinum thus obtained dissolves readily in aqua regia, giving a reddish-yellow solution containing hydrochlorplatinic acid, H_2PtCl_6, which should be evaporated nearly to dryness, at a moderate heat, treated with hydrochloric acid, and again evaporated. It should be finally taken up with a little water, filtered if necessary, and added to a concentrated solution of ammonium chloride, when a yellow precipitate of ammonium platinic chloride, $(NH_4)_2PtCl_6$, will be thrown down. The precipitate, if collected upon a filter, washed with alcohol, and ignited, yields a gray platinum sponge, containing often some other metals of the platinum group. Gold, if present, will be in the filtrate.

The Rarer Metals of the Platinum Group.

Ruthenium, Ru.—Atomic weight, 101.5.
Rhodium, Rh.—Atomic weight, 103.
Palladium, Pd.—Atomic weight, 106.5.
Osmium, Os.—Atomic weight, 190.8.
Iridium, Ir.—Atomic weight, 193.1.

OCCURRENCE.—All the above metals are found in small quantity in native platinum. Iridium and palladium, containing some platinum and traces of the other platinum metals, are found native. Iridosmine is a mixture consisting chiefly of iridium and osmium. Laurite is essentially RuS_2.

DETECTION.—The analysis of the platinum metals is one of the difficult problems of analytical chemistry for which advanced works on the subject should be consulted. A few special tests, however, will be given.

Osmium is characterized by a volatile oxide, OsO_4, which has an exceedingly penetrating and disagreeable odor, somewhat resembling bromine. The vapors are poisonous and should not be breathed too freely. The odor may be obtained by heating the powdered mineral in an open tube, and a very characteristic test may be made by bringing the upper end of the tube within a Bunsen-burner flame, so that the osmic oxide will pass into the latter, which will become luminous, owing to the reduction of the osmic oxide and to the glowing of the finely divided metallic osmium. The odor of osmium is also obtained when the finely divided mineral is oxidized by fusing in a bulb tube with sodium or potassium nitrate.

Iridium and *iridosmine* are characterized by their hardness (6–7) and insolubility in acids, even aqua regia failing to dissolve them. Iridium is partially oxidized by fusion with sodium nitrate (this may be done in a bulb tube), and the fused mass when boiled with aqua regia yields a deep red to reddish-black solution.

Native palladium exhibits a bluish tarnish, which is lost by heating in the reducing flame, the color becoming like that of platinum, but is regained by heating moderately in the air (best in an open tube). When a piece is flattened on an anvil to expose a maximum surface, and fused with potassium bisulphate, the metal is oxidized and dissolved to some extent. On soaking out the fusion in water, and adding a very small crystal of potassium iodide, a black precipitate of palladous iodide is formed, which dissolves in a large excess of potassium iodide, giving a deep wine-red color.

Potassium, K.—Univalent. Atomic weight, 39.1.

OCCURRENCE.—Potassium is a very abundant element, and, although its simple salts are soluble in water, it occurs in insoluble combinations in many silicates. Orthoclase, $KAlSi_3O_8$, is one of the most abundant minerals in the crust of the earth. The most important minerals for the production of potassium compounds are certain soluble chlorides (sylvite, carnalite), which are found in connection with deposits of rock salt.

DETECTION.—Flame coloration furnishes the most convenient means of testing for potassium, and, where this test cannot be applied, precipitation as potassium platinic chloride may be resorted to.

1. *Flame Test.*—Volatile potassium compounds color the flame pale violet, and the test may be made by introducing the substance, held in the forceps or in a loop on platinum wire, into the hottest part of the Bunsen-burner or blowpipe flame. The flame color is not very strong and is easily obscured by other elements, especially sodium, but by viewing it through blue glass of sufficient thickness, the disturbing colors may be absorbed, and the potash flame will be distinctly seen of a violet or purplish-red color, depending upon the depth of color of the glass.

a. Take up some sylvite, KCl, in a small loop on platinum wire, introduce it into a Bunsen-burner flame, and observe the color. Also examine the flame through various thicknesses of blue glass.

b. Add a little sodium chloride to the potassium chloride, and repeat the foregoing experiment.

c. In testing silicates from which, under ordinary conditions, the potassium is not readily volatilized, the following method will be found very useful: Mix the finely powdered mineral with an equal volume of powdered gypsum, and having heated a platinum wire until it gives no color to the flame, touch the end of it to a drop of water and then to the mixture, so as to take up a little of the latter. Introduce this carefully into the hottest part of a Bunsen-burner flame, and observe the color, making use of blue glass to absorb the yellow resulting from sodium, which is almost sure to be present, in traces at least, with potassium. Gypsum, when fused with the mineral, forms calcium silicate and potassium sulphate, and the latter, when it volatilizes, imparts the color to the flame. Instead of a straight wire, a small loop may be used for taking up the mixture, but it is necessary to have a heat sufficiently intense to fuse the minerals together and liberate the potassium sulphate. The test is quite delicate.

2. *Alkaline Reaction.*—With the exception of the silicates, phosphates, borates, and salts of a few rare acids, the potassium compounds become alkaline upon intense ignition before the blowpipe. The test is not so satisfactory as that made with minerals containing other alkalies and alkaline earths.

3. *Precipitation as Potassium Platinic Chloride.*—If hydrochlorplatinic acid, H_2PtCl_6, is added to a rather concentrated, neutral, or slightly acid solution containing potassium, a yellow crystalline precipitate of potassium platinic chloride, K_2PtCl_6, will be formed, which furnishes an excellent means for detecting potassium. The precipitate is sparingly soluble in water, and almost absolutely insoluble in alcohol. Ammonium compounds yield a similar precipitate, $(NH_4)_2PtCl_6$.

a. In order to make the test, dissolve a little sylvite, KCl, in a few drops of water, and then add a few drops of hydrochlorplatinic acid.

b. To adapt the test to insoluble silicates, proceed as follows: Fuse the powdered mineral with sodium carbonate, as described in detail under silicates (p. 110, § 4). Pulverize the fused mass, treat it in a test-tube with a little hydrochloric acid, evaporate to dryness, and after cooling add about 2 cc. of water and boil. Next add an equal volume of alcohol, filter through a small paper, and add a few drops of the hydrochlorplatinic acid solution to the filtrate in order to precipitate the potassium.

Rhodium, Rh.—See the rare metals of the platinum group, p. 104.

Rubidium, Rb.—Univalent. Atomic weight, 85.5.

OCCURRENCE.—This rare alkali metal is found very sparingly together with caesium in some varieties of lepidolite.

DETECTION.—Rubidium is very similar to potassium, and forms an insoluble platinic chloride, Rb_2PtCl_6. Examination with a spectroscope is needed for its identification.

Selenium, Se.—Bivalent and sexivalent. Atomic weight, 79.

OCCURRENCE.—This rare element is found usually in combination with the metals, as selenides; clausthalite, PbSe; tiemannite, HgSe, etc., which are analogous to sulphides.

DETECTION.—When a substance containing selenium is heated before the blowpipe on charcoal, a curious odor may be observed which is described by Berzelius as similar to that of radishes and also of decaying radishes. It is impossible to describe this odor, but only a few trials are necessary to render it familiar, and it is so pronounced and characteristic that a very minute quantity of selenium may be detected by means of it. If the selenium is present in considerable quantity, it volatilizes as a brownish smoke, and some of it deposits at a little distance from the assay as a silvery coating of oxide, SeO_2, which may have an outer border of red, owing to admixture of finely divided selenium. If the coating is touched with the reducing flame, the selenium volatilizes, and imparts a magnificent azure-blue color to the flame. This is an extremely delicate and characteristic test.

In the open tube, selenium yields a white oxide, SeO_2, which usually crystallizes in radiating prisms on the sides of the glass, and is reddened by an admixture of finely divided selenium. The sublimate is volatile, and, if driven up the tube, it may be made to give a beautiful blue color if the tube is held so that the vapors at the end pass into the reducing part of a Bunsen-burner flame.

In the closed tube, selenium volatilizes from some of its compounds, and condenses as black globules fused against the glass, but where the globules are very minute, they transmit some light and cause the thinnest part of the sublimate to appear red or brown. Owing to the air in the tube, a little oxide, SeO_2, may form, which crystallizes on the glass above the selenium.

Silicon, Si.—Tetravalent. Atomic weight, 28.

OCCURRENCE.—Next to oxygen, silicon is the most abundant element in the minerals which constitute the crust of the earth (p. 3). In combination with oxygen, it forms the very common mineral, quartz, SiO_2, and it is the characteristic non-metallic element in the silicates, or salts of silicic acid. Silicates are very numerous, and salts of several kinds or types of silicic acids are recognized, the most important of which are as follows:

Orthosilicic acid,	H_4SiO_4.
Metasilicic acid,	$H_4Si_2O_6 = 2H_2SiO_3$.
Trisilicic acid,	$H_4Si_3O_8$.
Tetrasilicic acid,	$H_4Si_4O_{10} = 2H_2Si_2O_5$.

The acids, written as above in a progressive series, differ from one another by addition of SiO_2. There are no methods for determining just what kind of silicic acid is contained in any given silicate except quantitative chemical analyses from which the ratio between the silica and the metals may be calculated (p. 6). For example, in forsterite, $Mg : Si = 2 : 1$, and, Mg being bivalent, the formula must be Mg_2SiO_4, a salt of orthosilicic acid. In orthoclase, $K : Al : Si = 1 : 1 : 3$, and potassium being univalent and aluminium trivalent, the formula is $KAlSi_3O_8$. In the majority of cases, the empirical formulae of the silicates have been determined with a fair degree of accuracy, and most of them have been found to correspond to the few types of acids already mentioned, the orthosilicates and metasilicates being the commonest. The formulae of some silicates, however, and among them a few of the common ones, are uncertain. The true constitution of the silicates, that is, their structural formulae or the manner in which the atoms are united to one another, is uncertain, and largely a matter of conjecture. It has been found that the metals sodium, potassium, calcium, magnesium, ferrous and ferric iron, and aluminium, are of very common occurrence in the silicates, and that orthosilicates are more soluble in acids than metasilicates and polysilicates.

Detection.—The surest method for the identification of a silicate is to get the mineral in solution in an acid, and obtain gelatinous silica by evaporation. The residue or skeleton of silica obtained in the salt of phosphorus bead furnishes a simple but not very delicate test.

1. *Formation of a Jelly.*—When a silicate is dissolved in acid the solution may be regarded as containing free silicic acid, possibly H_4SiO_4, and, upon evaporation, there comes a point when the latter can no longer remain in solution, but yields a

gelatinous mass. If the evaporation is continued until the mass becomes dry, and the latter is then moistened with strong acid and digested with water, the bases will go into solution, while the silica remains insoluble and may be separated by filtering. Comparative tests have shown that gelatinization is more readily obtained with nitric than with hydrochloric acid, although in many cases either will answer. As most silicates are insoluble in acids, a previous decomposition, by fusion with sodium carbonate, is usually necessary before applying the test (compare § 4).

To illustrate the foregoing, in the case of soluble silicates, take about 2 ivory spoonfuls of finely powdered calamine $(ZnOH)_2SiO_3$, or nepheline, essentially $NaAlSiO_4$, mix in a test-tube with about 1 cc. of water, then add 3 cc. of nitric or hydrochloric acid, warm, and observe that the mineral yields a perfectly clear solution. Boil the solution, and it will soon become thick from the separation of gelatinous silica. The gelatinous silica is insoluble in water and acids, and, if thoroughly washed with water and dried over sulphuric acid, has essentially the composition H_2SiO_3. The reason for adding the water at the beginning of this experiment is to thoroughly mix the mineral with the acid. If omitted, the acid when it first comes in contact with the dry material will often form a layer of gelatinous silica over the powder and prevent a portion of it from going into solution.

2. *Separation of Silica without Gelatinization.*—Some silicates are completely decomposed by boiling with acids, the bases going into solution, while the silica is left in an insoluble condition, but without any formation of a jelly. From the appearance of the test it is sometimes rather difficult to tell whether a mineral has been decomposed or not, but the separated silica, having a low index of refraction, makes the liquid in which it is suspended appear translucent and almost clear, while the fine, suspended powder of an insoluble mineral causes the liquid to appear white and milky. A sure test is to filter, and evaporate a drop of the solution on a piece of glass or platinum, when, if a considerable residue is left, it indicates that a decomposition has taken place, and the bases have gone into solution.

An experiment to illustrate the above may be made by boiling 2 ivory spoonfuls of finely powdered serpentine or stilbite with 5 cc. of hydrochloric acid.

3. *Fusion with Sodium Carbonate.*—When quartz, SiO_2, or a silicate is fused with sodium carbonate, a sodium silicate is formed. Moreover, the fused mass will be soluble in acids, and, upon evaporation of the solution, gelatinous silica separates, as in § 1. Fusion with sodium carbonate is indispensable for the solution and subsequent analysis of insoluble silicates (compare § 4).

To illustrate the foregoing paragraph, take some very finely powdered quartz, SiO_2, and an equal volume of sodium carbonate (rather less sodium carbonate than more), make into a paste with water, then support some of the mixture on a small loop on platinum wire and heat with an intense blowpipe flame. Instead of fusing on a platinum loop, the experiment succeeds beautifully when a minute quantity of the mixture is heated intensely on a clean charcoal surface. If successful, a transparent bead should result, and the experiment illustrates the process of glass-making. The sodium carbonate brings about a decomposition of the quartz, the anhydride of silicic acid, with the formation of sodium silicate and evolution of carbon dioxide gas, the reaction being somewhat as follows: $2Na_2CO_3 + SiO_2 = Na_4SiO_4 + 2CO_2$.

4. *Special Treatment for the Detection of the Common Elements in Silicates.*—The methods to be described are for the detection of aluminium, iron, calcium, and magnesium, which are very commonly present in silicates, but to devise a scheme applicable to all possible cases would require the elaborate methods of qualitative chemical analysis, which are beyond the scope of the present work. The scheme has been made as simple as possible, and the tests can be performed upon a small quantity of material and in a short time, but the beginner will find it necessary to follow the details quite closely.

If a silicate is insoluble in acids, it may be decomposed readily by fusion with sodium carbonate and then dissolved. For a test, mix a scant ivory spoonful of the finely powdered silicate with 3 parts of sodium carbonate, make into a paste with a drop of water and then take up a portion of the material on a loop on platinum wire and fuse before the blowpipe. Make two or three beads, if necessary, rather than attempt to fuse all of the material at once. In almost all cases there results after fusion an opaque mass, the presence of various oxides contained in the mineral, mixed with the sodium silicate and excess of sodium carbonate, preventing the formation of a clear glass as in § 3. The several beads, after removal from the platinum wire, are pulverized in a diamond mortar, transferred to a test-tube, treated with about 1 cc. of water and an equal volume of nitric acid, and evaporated to dryness, being careful toward the end of the operation not to allow the tube to become very hot. After cooling, moisten the contents of the tube with about 3 cc. of hydrochloric acid, boil for a few seconds, so as to decompose any basic salts formed during the evaporation, then add 5 cc. of water, heat to boiling, and remove the insoluble silica by filtering. The silica separated at this point should be white, and may be tested as follows: Wash well on the paper with water, but do not add the washings to the first filtrate, puncture the paper, and, by means of a jet of water, wash the silica into a clean test-tube, then add a little potassium hydroxide and boil, when the silica, if pure, will go wholly into solution.

The filtrate from the silica contains the bases, with the iron in the ferric condition, owing to the use of nitric acid. The solution is heated to boiling, and ammonia is added in slight excess to precipitate aluminium and ferric hydroxides (p. 42, § 2, and p. 87 § 5), which are collected on a filter and washed with water. If the precipitate is light-colored, iron is absent, or present only in small quantity; if it is reddish-brown, indicating iron, aluminium may be also present, and must be specially tested for, as follows: By means of a knife-blade or spatula scrape off the precipitate from the filter, and with the aid of a jet of water transfer it to a clean test-tube, or fold up the paper with the precipitate, and drop it into the test-tube. Have about 5 cc. of water present, then add some potassium hydroxide (a piece of stick potash 5 mm. long), and boil, by which treatment aluminium hydroxide is dissolved, and may be separated from the iron by filtering. The solution is made acid with hydrochloric acid, boiled, and ammonia added in excess, when aluminium, if present, will be precipitated. Whether ferrous or ferric iron is contained in the mineral must be determined by special tests (p. 85, § 4).

The filtrate from the iron and aluminium may contain calcium and magnesium (if much magnesium is present, some of it may have been precipitated by ammonia along with the iron and aluminium). It is heated to boiling, and a little ammonium oxalate added in order to precipitate the calcium (p. 60, § 6). Calcium oxalate is precipitated in a very finely divided condition, and is liable to run through filter-paper. It is best, therefore, to let the precipitate stand for about ten minutes before filtering, and then, if the filtrate is turbid, to pass it a second or third time through the same filter until the pores of the paper become stopped, and a clear filtrate is obtained. To the filtrate, a little ammonium oxalate is added to make sure of the complete precipitation of the calcium, and, if no precipitate forms, some sodium phosphate and strong ammonia are added to precipitate the magnesium (p. 91, § 1). If a precipitate does not form immediately, however, it must not be considered that magnesium is absent, for, if only a small quantity is present, and especially if the solution is warm, the precipitate may not appear until after standing some time in the cold. For alkalies, the tests given under sodium (p. 116, § 1, *c*) and potassium (p. 105, § 1, *c*) are recommended.

5. *Test with the Salt of Phosphorus Bead.*—Oxide of silicon dissolves with difficulty in a salt of phosphorus bead; therefore, when some powdered silicate is fused in the bead, the silica, SiO_2, is left as an insoluble skeleton or translucent mass, while the bases go into solution. The test may be recommended on account of its simplicity, but it is not delicate.

In order to test the above, touch the phosphorus bead when hot to any powdered silicate, so as to take up a quantity which before heating does not quite cover one half the surface of the bead, and then heat before the blowpipe, in the hottest part of the flame. As the bases dissolve in the hot glass, the silica moves about and collects together, and, when examined with a lens, it appears as a translucent mass, usually occupying a position in about the center of the bead, and is quite different in appearance from any undissolved mineral. Sometimes it is better to heat a *fragment* of the mineral in the bead, and after igniting for some time, the translucent silica skeleton may be seen surrounding a particle of the still undecomposed mineral.

6. *Decomposition with Borax.*— Silicates are quite soluble in a borax bead, and it may be sometimes found convenient to sub-

stitute this treatment for fusion with sodium carbonate in order to decompose a silicate.

Silver, Ag.—Univalent. Atomic weight, 108.

OCCURRENCE.—Some silver is found native and as chloride or bromide, but by far the greater part of the metal of commerce is obtained from its compounds with sulphur. A few of the most important silver minerals are argentite, Ag_2S; stromeyerite, $AgCuS$; pyrargyrite, $3Ag_2S.Sb_2S_3$; proustite, $3Ag_2S.As_2S_3$; stephanite, $5Ag_2S.Sb_2S_3$; polybasite, essentially $9Ag_2S.Sb_2S_3$; cerargyrite, $AgCl$; and embolite, $AgCl$ with $AgBr$. Silver is found in several combinations with tellurium, and in small quantity in many sulphides; as in galena, sphalerite, chalcocite, bornite, and tetrahedrite, which are then called *argentiferous*. Owing to the value of silver, it is profitable to extract it from ores which contain only a small percentage of the metal. An ore, for example, having one per cent of silver would yield 291 troy ounces of the metal per ton, and, under favorable conditions, ores containing less than one tenth of the above amount may be profitably worked.

DETECTION.—The metal is usually detected by reduction to the metallic state or by precipitation as silver chloride.

1. *Reduction to Metallic Silver.*—From pure silver minerals, the metal may be readily obtained on charcoal by fusion before the blowpipe with about 3 volumes of sodium carbonate. The metal easily fuses to a globule, and this is bright both while in the flame and after cooling, for the metal does not tend to oxidize. The silver globule is malleable, can be flattened by hammering on an anvil, and may be further tested according to § 3. When other readily reducible metals are present, the globule obtained by the above treatment will not be pure silver, and fusion with test-lead and cupellation on bone-ash (§ 2) may then be resorted to. Often fusion on a clean charcoal surface in the oxidizing flame with borax is sufficient to free the metal from impurities, since the foreign substances oxidize, dissolve in the borax, and leave finally a globule of pure silver. When in combination with only volatile elements

(sulphur, arsenic, antimony), a silver globule may be obtained by heating some of the mineral alone on charcoal in the oxidizing flame. Silver is volatile to a slight degree, but alone on charcoal it gives no characteristic coating. When silver is associated with lead and antimony, however, the coatings which these latter elements give on charcoal assume a reddish to deep lilac tint, which serves as a very certain indication of the presence of silver.

2. *Cupellation on Bone-ash and Detection of Small Quantities of Silver.*—A method well adapted for the detection of even very small quantities of silver in minerals or ores is to mix an ivory spoonful of the finely powdered material with an equal volume each of borax glass and test-lead, transfer to a rather deep, funnel-shaped cavity in a compact piece of charcoal, and fuse before the blowpipe for some time in a reducing flame until the lead, which takes up all the silver, has united into one globule, while the impurities dissolve in the borax. Later an oxidizing flame may be used in order to form lead oxide, which dissolves in the borax and assists in taking up the impurities. After cooling, the lead is removed from the charcoal, and freed from adhering slag by hammering on an anvil. A cupel is next prepared by filling a cavity on charcoal with bone-ash, and pressing the latter down firmly by means of an agate pestle or other smooth rounded surface, such as the back of the metal scoop (Fig. 22), so as to form a shallow depression about 15 mm. in diameter. Loose particles of bone-ash are removed by inverting and gently tapping the charcoal, and the cupel is heated intensely before the blowpipe in order to expel moisture. The lead button is then placed carefully upon the cupel, so as not to disturb the surface of the bone-ash, and fused before the blowpipe, first in the reducing flame until a bright metallic surface is obtained, and then in a small oxidizing flame (Fig. 41). It is necessary to heat in the oxidizing flame for several minutes in order to oxidize the lead, during which time the surface of the button shows a play of rainbow colors, due to a thin film of lead oxide, which constantly flows to the sides, and is absorbed by the bone-ash. Finally, when the last of the lead is oxidized, the play of color ceases, the globule is said to "*blick*," and the operation is completed. Frequently the amount of lead oxide formed is so great that it cannot all be absorbed by one cupel. The button then becomes surrounded by, and seems to float upon, the fused lead oxide, and when this happens, it is best to interrupt the operation and oxidize the last of the lead upon a fresh cupel.

Considerable practice is needed in order to make the silver assay easily and quickly, but when the necessary skill has been acquired, the operation may be performed in less than fifteen minutes, and by assaying samples of known value and saving the silver beads for comparison, one can soon learn to judge of the relative values of ores. By starting with weighed quantities of material, and especially by making use of the special apparatus mentioned in Plattner's elaborate treatise,* very good quantitative determinations of silver may be made by means of the blowpipe assay.

3. *Precipitation as Silver Chloride.*—Silver chloride, AgCl, is very insoluble in water and dilute nitric acid. A white precipitate of silver chloride will therefore form if silver is dissolved in dilute nitric acid ($1HNO_3 : 2H_2O$) and a few drops of hydrochloric acid are added to the solution. If the quantity of the precipitiate is small it appears as a turbidity, while if it is considerable it collects as a curdy mass. It darkens on exposure to light and is readily soluble in ammonia. A globule of silver from one of the foregoing experiments may be tested in this way. It is also often convenient to test for silver by dissolving a mineral in hot, concentrated, nitric acid, and, after dilution, and filtering if necessary, to precipitate the silver with hydrochloric acid. The precipitate, if collected on a filter, may be tested according to § 1.

Sodium, Na.—Univalent. Atomic weight, 23.

OCCURRENCE. — Sodium is a very abundant element, and although its simple salts are all soluble in water and are not ordinarily found as minerals in wet regions, they often accumulate in desert or dry places, and form deposits of great commercial value. The most important compound is halite, NaCl, which is found both as rock salt and in solution in the water of the oceans. Double salts containing sodium, which are insoluble in water and often also in acids (for example, albite, $NaAlSi_3O_8$), are very common, especially in the group of silicates.

DETECTION.—Sodium is usually detected by means of the flame coloration and alkaline reaction.

1. *Flame Test.*—Volatile sodium compounds color the flame yellow, and the test is exceedingly delicate. The color is monochromatic, and therefore shows only a single band in the spectroscope. The flame color cannot be seen through moderately dark blue glass, as the yellow rays are wholly absorbed (see Potassium, p. 105, § 1).

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* Probirkunst mit dem Löthrohre. American translation by Cornwall.

a. To illustrate the above, fuse in the forceps some halite or cryolite before the blowpipe, or, still better, fuse some of the material into a loop on platinum wire and introduce it into a Bunsen-burner flame at about the point *r*, Fig. 35, p. 32.

b. To illustrate the great delicacy of the reaction, heat a platinum wire until it gives no color to the flame, then draw it through the fingers, heat again, and observe the yellow color which results from the minute trace of sodium derived from contact with the fingers. The flame test is so exceedingly delicate that a great deal of judgment must be exercised in making use of it. A mineral should be regarded as containing sodium only when it gives an intense and prolonged yellow coloration, as in the previous test.

c. Silicates from which sodium is not readily volatilized may be fused with gypsum, as directed under potassium (p. 105, § 1, *c*).

2. *Alkaline Reaction.*—With the exception of the silicates, phosphates, borates, and the salts of a few rare acids, sodium compounds become alkaline upon ignition before the blowpipe. A similar reaction is obtained from other minerals containing the alkalies and alkaline earths.

a. Make a loop about 3 mm. in diameter on platinum wire, fuse some halite in it, and continue to heat for some time, but not long enough to volatilize all the material. In order to test the alkaline reaction, bring the fused mass in contact with a piece of moistened turmeric-paper on a clean glazed surface. In this experiment, water (one of the products of combustion) acting at a high temperature brings about a partial decomposition of the material, as follows: $NaCl + H_2O = NaOH + HCl$.

b. If a fragment of cryolite, Na_3AlF_6, is fused in a loop on platinum wire and heated before the blowpipe, the hydrofluoric acid which is driven off may be readily detected by its pungent odor, or by the reddening of a moistened blue litmus-paper held at a little distance beyond the flame, while the residue will impart an alkaline reaction to moistened turmeric-paper.

Strontium, Sr.—Bivalent. Atomic weight, 87.5.

OCCURRENCE.—Strontium is found quite abundantly as celestite, $SrSO_4$, and strontianite, $SrCO_3$, but other combinations are rare (brewsterite).

DETECTION.—Strontium is usually detected by the flame coloration, alkaline reaction after heating, and by precipitation as sulphate.

1. *Flame Test.*—Strontium compounds when heated before the blowpipe impart a crimson color to the flame, and this may be ob-

tained by igniting fragments held in the platinum-pointed forceps, or often still better by taking up some of the powdered mineral on platinum wire, as directed on p. 35, and heating before the blowpipe or in the Bunsen-burner flame. Often the coloration can be made more intense by moistening the material with hydrochloric acid. The crimson flame must not be mistaken for lithium, or, in case hydrochloric acid is used, for the yellowish-red of calcium (p. 59, § 2), which, however, is not as persistent on prolonged heating as the crimson of strontium. A spectroscope can be used to advantage.

2. *Alkaline Reaction.*—Strontium compounds become alkaline upon ignition before the blowpipe, with the exception of the silicates and phosphates (compare Calcium, p. 58, § 1). A similar reaction is obtained from other minerals containing the alkalies and alkaline earths. There are no lithium minerals known which yield an alkaline reaction after ignition, and therefore a crimson flame in connection with alkaline reaction is an almost certain proof of the presence of strontium.

3. *Precipitation as Strontium Sulphate.*—Strontium sulphate, $SrSO_4$, is very insoluble in water and dilute acids, and may be precipitated by adding a few drops of *dilute sulphuric acid* to solutions, provided the latter are not *very* dilute and do not contain too much acid. The test will be found convenient in distinguishing strontium from lithium and calcium, and for the detection of strontium in silicates and phosphates which do not yield a flame coloration or alkaline reaction (compare Barium, p. 53, § 3, *b*).

Dissolve an ivory spoonful of strontianite in 3 cc. of warm hydrochloric acid, divide the solution into 2 parts, dilute one with about 5, and the other with 15 cc. of water, and add a few drops of dilute sulphuric acid to each. In the more concentrated solution, the precipitate forms almost immediately, but in the other, only after standing for several minutes, while an experiment made in exactly the same manner with calcite, $CaCO_3$, would not yield a precipitate of $CaSO_4$ in either solution (see p. 59, § 3). In order to precipitate strontium completely as sulphate, it is necessary to add an equal volume of alcohol to the liquid.

4. *Specific Gravity.*—Strontium compounds are heavy, and their specific gravities lie between those of the corresponding calcium and barium salts, as the following examples show:

	Specific Gravity.		Specific Gravity.
Aragonite, $CaCO_3$	2.95	Anhydrite, $CaSO_4$,	2.98
Strontianite, $SrCO_3$,	3.70	Celestite, $SrSO_4$,	3.96
Witherite, $BaCO_3$,	4.35	Barite, $BaSO_4$,	4.48

Sulphur, S.—Bivalent and sexivalent. Atomic weight, 32.

OCCURRENCE.—In addition to being found native, sulphur also occurs in two very important classes of compounds, the *sulphides* and *sulphates*. The sulphides may be generally regarded as salts of the weak acid, hydrogen sulphide, H_2S, and the common ores of many of the valuable metals are of this class; as argentite, Ag_2S; galena, PbS; sphalerite, ZnS; cinnabar, HgS, etc. The sulphates are salts of sulphuric acid, H_2SO_4, and the metals calcium, strontium, barium, and lead, form insoluble sulphates, which occur abundantly in nature. Soluble sulphates, especially those of the alkali metals, may accumulate in arid regions, and a number of double salts and basic sulphates are known. Sulphur is found rarely in combination with a silicate; as in helvite, $Mn_2(Mn_2S)Be_3(SiO_4)_3$ and noseite, $Na_4(NaSO_4Al)Al_2(SiO_4)_3$.

SULPHIDES.

DETECTION.—Sulphides may be most conveniently detected by an oxidizing process, such as roasting in the open tube or on charcoal.

1. *Oxidation or Roasting in the Open Tube.*—An exceedingly delicate test for a sulphide is to heat some of the finely powdered mineral in an open tube, when sulphur dioxide, SO_2, and usually an oxide of the metal are formed. Sulphur dioxide, the anhydride of sulphurous acid, is a colorless gas, which may be readily detected by its sharp, pungent odor and the acid reaction which it imparts to a piece of moistened litmus-paper placed at the end of the tube.

According to the directions given on p. 19, heat about $\frac{1}{16}$ of an ivory spoonful of finely powdered galena in an open tube until the odor of sulphur dioxide (burning sulphur) ceases, and the dark lead sulphide has changed wholly to light-colored lead oxide. The reaction is essentially as follows: $PbS + 3O = PbO + SO_2$. Lead oxide and sulphur dioxide combine to form a rather volatile product, and a trace of this will usually be found as a white sublimate a little above the lead oxide. The open-tube test is so delicate that when a minute particle of a sulphide is used, an acid reaction will be imparted to test-paper and usually even the odor of SO_2 will not escape detection.

When sulphides of iron, copper, and some other metals are roasted in the open tube, the oxides of the metals which are formed during the operation act as *oxidizing agents,* and convert some SO_2 to SO_3, the anhydride of sulphuric acid: $Fe_2O_3 + SO_2 = 2FeO + SO_3$. The formation of SO_3 is indicated by white fumes passing up the tube, and some of the SO_3 derives sufficient moisture from the atmosphere to form a little H_2SO_4 which condenses as a liquid in the tube.

2. *Oxidation or Roasting on Charcoal.*—An excellent method for detecting sulphur, but not so delicate as the one just given, is to roast the finely powdered sulphide on charcoal according to the directions given on p. 39, and observe the odor of SO_2. This test is especially recommended for sulphides which contain a great deal of sulphur.

3. *Roasting in the Platinum Forceps.*—Some sulphides oxidize so readily that, when held in the forceps and heated before the blowpipe, they take fire and continue to burn for some time, giving a strong odor of SO_2. Pyrite, FeS_2, and chalcopyrite, $CuFeS_2$, can be tested in this way.

4. *Heating in a Closed Tube.*—Many sulphides suffer no decomposition when heated in a closed tube, while others part with a portion of their sulphur, which condenses on the walls of the tube as a fused sublimate, having a dark amber color when hot, changing to pale yellow and becoming crystalline when cold. A sulphide of the metal always remains in the tube, and the test, although admirable for some sulphides, is not applicable in all cases. Owing to the air in the tube, there will always be some oxidation and formation of a little SO_2, but necessarily this must be trifling in amount, since there is no free circulation of the air and only about one fifth of it is oxygen.

Excellent experiments for illustrating the behavior of different sulphides may be made by heating fragments of pyrite, FeS_2, and galena, PbS, in

separate tubes. The first gives an abundant sublimate of sulphur, but sulphide of iron, FeS, is left in the tube, as may be proved by removing some of the material and roasting on charcoal or in the open tube. The galena, on the other hand, gives no sublimate, as there is no excess of sulphur above the normal sulphide, PbS.

5. *Test on Silver after Fusion with Sodium Carbonate.*—When a powdered sulphide is mixed with about 3 parts of sodium carbonate and fused before the blowpipe on charcoal, sodium sulphide will be formed, owing to the strong chemical affinity of sodium for sulphur. If some of the fused mass or of the charcoal into which it has been absorbed is placed with a drop of water on a clean silver surface, a black stain of silver sulphide will be formed. The test is so delicate that, if sodium carbonate is heated alone on charcoal before the blowpipe for a long time with a gas flame, and then placed upon moistened silver, a slight discoloration may result from the traces of sulphur contained in the gas and charcoal, but it is not necessary to mistake this slight discoloration for the strong reaction given by sulphides. If selenium and tellurium are present, the test cannot be relied upon.

6. *Oxidation and Solution by Means of Nitric Acid.*—Nitric acid, owing to its *strong oxidizing action*, serves as the best solvent for sulphides. If hot, concentrated acid is used, there are two processes to be considered, which go on simultaneously ; (1) *oxidation*, and (2) solution of the products of oxidation. The final products may be generally regarded as *sulphuric acid* and *nitrates of the metals.* For example, pyrite, FeS_2, is oxidized to *sulphuric* anhydride, SO_3, and *ferric* oxide, Fe_2O_3, and the first of these combines with water to form sulphuric acid, H_2SO_4, while the second dissolves in the nitric acid to form ferric nitrate, $Fe(NO_3)_3$. Since the metals oxidize more readily than sulphur, it frequently happens that a portion of the latter separates in a free state as a spongy mass. This separated sulphur oxidizes very slowly, and is yellow if pure, but is frequently black, owing to some undecomposed sulphide, which is held mechanically in the sulphur and is thus protected from the action of the acid. When a sulphide is decomposed with concentrated nitric acid, *no volatile sulphur com-*

pounds are formed, but all the sulphur remains either oxidized to sulphuric acid or partly separated in the free state.

While oxidation is going on, the nitric acid must suffer decomposition, but this may take place in different ways; for example, $2HNO_2 = O + 2NO_2 + H_2O$, or $2HNO_3 = 3O + 2NO + H_2O$. In either case, red vapors of NO_2 will be visible, for, provided the decomposition takes place according to the last equations, the colorless gas, NO, takes on oxygen as soon as it comes in contact with the air, and changes to NO_2. Since in the solution of sulphides in nitric acid there is no certainty regarding the exact manner in which the acid will break up in order to bring about the oxidation, it is scarcely practical to express the reaction by means of equations, but when red fumes of NO_2 gas are abundantly given off, it is a sure indication that *oxidation* is going on.

a. In order to illustrate this, treat about ½ ivory spoonful of powdered pyrite in a dry test-tube with 3 cc. of concentrated nitric acid, and boil until the evolution of red fumes ceases. The red fumes indicate that an oxidation is going on, and, if the experiment is successful, the mineral should be completely dissolved. Dilute the solution with 10 cc. of water, mix thoroughly, and test the greater part of it in a separate test-tube with a little barium chloride, when a white precipitate of barium sulphate will be thrown down (p. 122, § 1), indicating that sulphuric acid was formed. Dilute the remainder of the solution still further with water, divide into 2 portions, and test for ferric and ferrous iron according to p. 85, § 4. By this means it may be proved that the metal, as well as the sulphur, has been converted into the higher state of oxidation.

b. To illustrate the separation of free sulphur, and how this is dependent upon the character of the minerals, decompose equal portions of pyrite, FeS_2 (53.4% S), and pyrrhotite, $Fe_{11}S_{12}$ (38.4% S), in separate test-tubes with nitric acid, and make the conditions of the experiments as nearly alike as possible. Observe that the pyrrhotite with the least sulphur is the most difficult to dissolve completely, and that by its decomposition sulphur is separated, while the pyrite with the most sulphur dissolves completely. A possible explanation of this is that pyrrhotite, which is easily soluble in non-oxidizing acids (hydrochloric, for example), with evolution of H_2S, is at first decomposed by the nitric acid, giving H_2S, which is instantly oxidized to $H_2O + S$; while pyrite, which is insoluble in non-oxidizing acids, is oxidized by the concentrated acid without any intermediate formation of H_2S.

7. *Solution in Hydrochloric Acid.*—Most sulphides are either insoluble or difficultly soluble in hydrochloric acid, but those which

dissolve always give hydrogen sulphide gas, H_2S. The reaction is usually a simple one. $FeS + 2HCl = FeCl_2 + H_2S$. Hydrogen sulphide is readily recognized by its offensive odor.

Treat some finely powdered pyrrhotite, $Fe_{11}S_{12}$ (almost FeS), in a test-tube with 3 cc. of hydrochloric acid, and observe that a gas is evolved which has a disagreeable odor.

SULPHATES.

DETECTION.—Either the barium chloride test, or the one on silver after a sulphide has been formed by reduction, may be used for the detection of sulphates. The oxidation and roasting processes used for the detection of sulphur in sulphides *cannot* be applied to sulphates, as they are already oxidized.

1. *Test with Barium Chloride.*—If barium chloride is added to a dilute hydrochloric acid solution of a sulphate, a white precipitate of barium sulphate, $BaSO_4$, will form, which is almost absolutely insoluble in water and dilute acids, and serves therefore as a very delicate test for sulphates.

If the sulphate proves to be an insoluble one, test according to § 2, or fuse some of it in a platinum spoon with 6 parts of sodium carbonate, soak out the fusion with water, filter, make the filtrate slightly acid with hydrochloric acid, boil, and then test with barium chloride.

Illustrate the foregoing test by dissolving ½ ivory spoonful of gypsum, $CaSO_4.2H_2O$, in warm, dilute hydrochloric acid, and test the solution with a little barium chloride.

It is always best to dilute the acids before testing for a sulphate, for if barium chloride is added to concentrated hydrochloric or nitric acid, barium chloride or nitrate, both of which are insoluble in concentrated acids, might be thrown down, and mistaken for barium sulphate. They differ from the latter, however, in that they dissolve readily upon addition of water.

2. *Test on Silver after Reduction to Sulphide.*—If a powdered sulphate, mixed with an equal volume of charcoal powder and 2 of sodium carbonate, is made into a paste with water and fused on

platinum wire before the blowpipe until effervescence ceases, the sulphate will undergo decomposition and *reduction*, and sodium sulphide, Na_2S, will be formed. That reduction has taken place may be told by removing the bead from the wire, crushing it, and placing the material with a drop of water on a clean silver surface. Sodium sulphide will thus react with the silver and make a black stain of silver sulphide, as follows: $Na_2S + 2Ag + H_2O + O = Ag_2S + 2NaOH$. The test is exceedingly delicate (see p. 120, § 5), and, although it proves the presence of sulphur in a compound, it is not necessarily a test for a *sulphate*, unless it has been proved by a previous oxidizing experiment or by other means that the mineral is not a *sulphide*.

As an experiment, test barite, $BaSO_4$, as directed above. The reaction which goes on during fusion is as follows: $BaSO_4 + Na_2CO_3 + 2C = Na_2S + BaCO_3 + 2CO_2$. Besides testing on silver, take some of the crushed product, resulting from fusion with sodium carbonate and charcoal, and digest it in a test-tube with a few drops of water, then add a few drops of hydrochloric acid, and observe the odor of the escaping hydrogen sulphide gas, which will serve as a certain proof that the sulphate has been reduced to a sulphide.

3. *Closed-Tube Reactions.*—The common sulphates, those of the alkalies, alkali earths, and lead, suffer no decomposition when heated in a closed tube, while sulphates of the less basic elements, such as aluminium, iron, and copper, are more or less decomposed, yielding sulphuric anhydride, SO_3, or sulphurous anhydride, SO_2, or both. As water of crystallization is usually present in the latter compounds, it is also driven off and is made strongly acid by the oxides of sulphur (compare p. 82, § 2).

Tantalum, Ta.—Pentavalent. Atomic weight, 182.6.

Occurrence.—Tantalum is associated with niobium in the group of minerals known as the tantalates and niobates (see Niobium, p. 98).

Detection.—There are no simple tests for the detection of tantalum, but if niobium is found in any compound, it is almost certain that tantalum is also present. Tantalates are characterized by high specific gravities, greater than those of the corresponding niobium compounds.

In order to make a definite test for tantalum, separate the mixed tantalic and niobic oxides by fusion with potassium bisulphate, and treatment as directed on p. 99, § 2. Treat the oxides in a platinum dish with a little pure hydrofluoric acid, filter if necessary, and add a little potassium fluoride. Evaporate the solution in a water-bath nearly, but not quite, to dryness, dissolve the residue in the smallest possible quantity of boiling water, and allow the solution to become cold, when, if tantalum is present, a very characteristic double salt, K_2TaF_7, crystallizes out in fine needles. The crystals, if collected on a filter-paper and dried, have the appearance of wool. It is necessary that the hydrofluoric acid should be free from hydrofluosilicic acid (alone it should give no precipitate with potassium fluoride), and platinum or silver vessels must be used.

Tellurium, Te.—Usually bivalent in minerals. Atomic weight, 125.

OCCURRENCE.—Tellurium is found as the native element, but more often it is combined with the metals in tellurides, and it occurs rarely as tellurous oxide and salts of tellurous and telluric acids. The tellurides are analogous to the sulphides, and some of the more important ones are tetradymite, Bi_2Te_3; hessite, Ag_2Te; altaite, PbTe; sylvanite, $(Au,Ag)Te_2$; and calaverite, $AuTe_2$. Tellurium is the only element with which gold has been found in minerals, in chemical combination.

DETECTION.—A very delicate test for tellurium or tellurides may be made by heating a little of the finely powdered mineral in a test-tube with about 5 cc. of concentrated sulphuric acid, when the latter assumes a beautiful reddish-violet color. After cooling, addition of water will cause the color to disappear, and a grayish-black precipitate of tellurium will be thrown down.

Another test, applicable to all compounds containing tellurium, is to heat a mixture of the finely powdered substance with sodium carbonate and a little charcoal dust, in a rather large closed glass tube, by which means sodium telluride is formed, and after cooling and addition of water, the solution will assume a reddish-violet color. If a few drops of the solution are transferred to a porcelain plate or watch-glass by means of a pipette, the color soons disappears, and a gray precipitate of tellurium forms, owing to the oxidizing action of the air. The color disappears still more quickly if air is blown through some of the solution.

By heating in the open tube, tellurium and the tellurides are oxidized, and yield TeO_2, which passes up the tube as a white smoke, but mostly condenses near the heated part as a white sublimate. On heating the latter, it volatilizes very slowly, and fuses into globules, which are yellow when hot, and white or colorless when cold.

Heated in the closed tube, tellurium volatilizes and condenses on the hot glass as fused globules having a metallic luster. Accompanying the tellurium are white or colorless globules of the oxide, TeO_2, formed from the oxidation, due to the air in the tube.

Heated before the blowpipe on charcoal, tellurium is volatilized, and condenses near the heated part as a white sublimate of TeO_2, somewhat resembling antimony oxide. Some tellurium may escape oxidation, and condense as a slight brownish coating distant from the assay. The sublimates volatilize when heated before the blowpipe and impart a pale greenish color to the reducing flame.

Thallium, Tl.—Univalent and trivalent. Atomic weight, 203.6.

OCCURRENCE.—Thallium is a very rare element, and thus far only two minerals containing it in considerable quantity have been observed, crookesite, $(Cu,Tl,Ag)_2Se$, and lorandite, $TlAsS_2$, both of which are exceedingly rare.

DETECTION.—Thallium and its salts are quite volatile when heated before the blowpipe, and impart an intense green color to the flame. When the thallium flame is examined with the spectroscope, it shows only one bright green band. Heated before the blowpipe on charcoal in the reducing flame, thallium compounds yield a slight white coating of thallium oxide. Heated on charcoal in the oxidizing flame, with potassium iodide and sulphur, a yellowish-green coating, resembling lead iodide, is obtained, but this may be readily distinguished from the latter by the flame coloration.

Thorium, Th.—Tetravalent. Atomic weight, 233.

The reactions for this rare element are given under Cerium.

Tin, Sn.—Tetravalent in minerals. Atomic weight, 119.

OCCURRENCE.—Tin is found chiefly as the oxide cassiterite, SnO_2. Its combinations with sulphur and sulphides of the metals, the *sulphostannates* (stannite, Cu_2FeSnS_4, and canfieldite, Ag_8SnS_6), are rare. Nordenskiöldine is, perhaps, a basic stannate, $Ca(BO)_2SnO_4$. Traces of tin are found in many columbates and tantalates.

DETECTION.—Tin is usually detected by the formation of metallic globules by reduction on charcoal.

1. *Reduction on Charcoal.*—If ¼ ivory spoonful of finely powdered tin oxide is mixed with an equal volume of powdered charcoal and 2 of sodium carbonate, made into a paste with water, and then heated on charcoal in the reducing flame, the tin will be read-

ily reduced, and collect into globules, which are bright when covered with the reducing flame, but become coated with a film of oxide on exposure to the air. If heated intensely before the blowpipe, and for a considerable time, sufficient tin may volatilize to give a rather conspicuous white coating of oxide, SnO_2, on the charcoal. Tin globules are readily fusible, malleable, and, if cut, they show a white metallic color. If treated with a little, moderately concentrated, warm, nitric acid, they do not dissolve, but are oxidized to a white hydroxide (metastannic acid). Tin must not be confounded with other elements which give metallic globules on charcoal. It may be distinguished from lead and bismuth by the absence of a yellow coating of oxide on the charcoal, and from silver by the coating of oxide which forms both on the charcoal and over the surface of the globules.

Sodium carbonate and oxide of tin, when heated together without the addition of charcoal powder, usually form an infusible mass which is very difficult to reduce.

2. *Oxidation with Nitric Acid.*—The action of nitric acid upon metallic tin was mentioned in the previous paragraph. Sulphides of tin (the sulphostannates), if pulverized and treated with nitric acid, yield the insoluble metastannic acid, and after evaporating off most of the nitric acid and diluting with water, this may be collected on a filter, washed with water, and tested according to § 1.

3. *Detection of Small Quantities of Tin.*—Mix 1 or 2 ivory spoonfuls of the finely powdered mineral with 6 volumes each of sodium carbonate and of sulphur, transfer the mixture to a porcelain crucible, cover, and heat gently at first, finally for five or ten minutes at a red heat. On cooling, treat the fused mass with warm water, which dissolves sodium sulphostannate, while most other substances which are apt to be present will be insoluble. Filter, and by adding sulphuric acid to the filtrate, precipitate the tin as sulphide, which will be accompanied by much free sulphur. Collect the precipitate on a filter, wash several times with water, ignite in a crucible to get rid of the free sulphur and the paper, and test the residue before the blowpipe on charcoal, according to § 1. If a porcelain crucible is not at hand, the fusion with sodium carbonate and sulphur may be made in a large bulb tube or even in a test-tube.

When niobates and tantalates are fused with potassium bisulphate and treated as directed on p. 99, § 2, the oxides of tin and tungsten remain with the niobic and tantalic oxides, and these may be separated either by the sodium carbonate and sulphur fusion, or by digestion of the moist oxides with ammonium sulphide. After filtering, precipitate the tin and tungsten by addition of sulphuric acid, collect the precipitate on a filter, wash, ignite, and test for tin, as directed in § 1.

Titanium, Ti.—Tetravalent and trivalent. Atomic weight, 48.

OCCURRENCE.—Although usually classed among the rare elements, titanium is quite common, and is always found in combination with oxygen. Rutile, octahedrite, and brookite, which are different crystalline forms of TiO_2; ilmenite, or titanic iron (a combination of the oxides of iron and titanium); and titanite, $CaTiSiO_5$, are the commonest titanium minerals. Some titanium, either in the form of ilmenite, titanite, or rutile, is present in most igneous rocks.

DETECTION.—Titanium may be detected by the salt of phosphorus bead, the reduction with metallic tin, or oxidation with hydrogen peroxide.

1. *Test with Salt of Phosphorus.*—Oxide of titanium, if dissolved in a salt of phosphorus bead in the oxidizing flame, gives a glass which is yellow when hot, and colorless when cold, while in the reducing flame the glass is yellow while hot, but on cooling assumes a delicate violet color, due to the presence of Ti_2O_3. Since the color is never very intense, and the presence of other substances which color the bead interferes with it, one of the tests given beyond will usually be found more satisfactory.

No decisive test can be made with borax.

2. *Reduction with Tin.*—Most titanium minerals are very insoluble in acids, but after fusion with sodium carbonate, they go readily into solution in hydrochloric acid, and the solution contains $TiCl_4$. If this acid solution is boiled with a little granulated tin, the titanium is reduced to $TiCl_3$, which causes the solution to assume a delicate violet color. Other substances with which titanium is apt to occur do not interfere, and the test is quite delicate, but if a substance is supposed to contain less than 3 per cent of TiO_2, the test with hydrogen peroxide is to be preferred.

To illustrate this test, mix ½ ivory spoonful of the finely powdered mineral (rutile or ilmenite) with 6 volumes of sodium carbonate, make into a paste with water, and fuse before the blowpipe either on platinum wire or charcoal. Oxide of titanium, which is an acid anhydride, is decomposed readily by sodium carbonate, with formation of sodium titanate, $TiO_2 + 2Na_2CO_3 = Na_4TiO_4 + 2CO_2$, and the latter is easily dissolved by hydrochloric acid. $Na_4TiO_4 + 8HCl = TiCl_4 + 4NaCl + 4H_2O$. Treat the fusion in a test-tube with about 5 cc. of strong hydrochloric acid, boil until a solution is obtained, filter if necessary, then add a little granulated tin, and boil until the violet color makes its appearance. If the quantity of titanium is small, it is necessary to boil the liquid away until only 1 or 2 cc. are left. The color is seen best when the acid becomes cold, and the evolution of hydrogen ceases. If much titanium is present, sometimes on boiling, a portion of it will precipitate as oxide, but enough will always remain in solution to give the violet color.

In testing niobates and tantalates for titanium, it is best to fuse the material with borax, as directed on p. 98, § 1, and on dissolving the fusion in hydrochloric acid and boiling with tin, the violet color of titanium will appear before the blue of niobium.

3. *Test with Hydrogen Peroxide.*—For this exceedingly delicate test, the mineral must be dissolved in sulphuric acid, which may be accomplished by first fusing with sodium carbonate, as previously directed, treating the fusion in a test-tube with 1 cc. of concentrated sulphuric acid and 1 cc. of water, and heating until the solution becomes clear. When cold, water is added, then some hydrogen peroxide, and if titanium is present, the solution becomes reddish-yellow to deep amber, depending upon the quantity of the titanium in the solution.

Tungsten, W.—Sexivalent. Atomic weight, 185.

Occurrence.—Tungsten is the acid-forming element in a group of minerals known as the tungstates, the most important of which are wolframite, $(Fe,Mn)WO_4$; hübnerite, $MnWO_4$; and scheelite, $CaWO_4$. The element is found in small quantity in a number of the niobates and tantalates.

Detection.—1. When a tungstate is decomposed by boiling with hydrochloric acid, an insoluble, canary-yellow, tungstic oxide, WO_3, is obtained, and if after the addition of a little granulated tin, the boiling is continued, a blue color is at first obtained ($2WO_3 + WO_2$), and this by further reduction finally changes to brown (WO_2). Another very good way to test, after having decomposed the mineral with hydrochloric acid, is to collect the

WO_3 on a filter, dissolve some of it in ammonia, acidify with hydrochloric acid, which usually causes a white or yellowish turbidity, and then boil with granulated tin. When a blue color has been obtained, dilute with water, when it will be found that the color does not disappear (compare Niobium), and that it is due to an insoluble compound suspended in the liquid.

2. If the tungstate is insoluble or difficultly soluble in hydrochloric acid (wolframite), mix the fine powder with 6 volumes of sodium carbonate, make into a paste with water, fuse in a loop on platinum wire, pulverize, and dissolve in a test-tube in a little water. The sodium tungstate formed during fusion is soluble in water (difference from niobium); it may be separated from the bases by filtering, and, on acidifying the filtrate with hydrochloric acid and boiling with tin, the blue reduction test may be obtained.

3. In the salt of phosphorus bead in the oxidizing flame, oxide of tungsten gives no color, but in the reducing flame, the bead becomes fine blue. The reactions with borax are not satisfactory.

4. In order to detect the small quantity of tungsten in niobates and tantalates, treat the oxides obtained by the potassium bisulphate fusion (p. 99, § 2) either with ammonium sulphide or a sodium carbonate and sulphur fusion, separate the tungsten exactly as described for tin (p. 126, § 3), and then test by the foregoing methods.

Uranium, U.—Tetravalent and sexivalent. Atomic weight, 240.

OCCURRENCE.—This rare element is found as an essential constituent in only a few minerals (uranite, gummite, uranosphaerite, torbernite, autunite), while it occurs sparingly in a number of others, especially those containing the rare elements niobium, tantalum, thorium, zirconium, cerium, lanthanum, didymium, yttrium, and erbium; as fergusonite, samarskite, euxenite, and polycrase.

DETECTION.—1. The reactions with the salt of phosphorus bead usually serve for the detection of uranium. In the oxidizing flame, the oxide is soluble to a clear yellow glass, which becomes yellowish-green on cooling, while after heating in the reducing flame, the bead assumes a fine green color. With borax, the colors are not so decisive, and are nearly like those of iron, being in the oxidizing flame reddish-yellow when hot, fading to yellow when cold, and in the reducing flame, very pale green, fading to almost colorless.

2. In the presence of other elements which impart color to the fluxes, and for the detection of small quantities of uranium in minerals, it is best to proceed as follows: Make a solution in hydrochloric acid (after fusion with sodium carbonate, if necessary, as directed under silicates, p. 110, § 4, or with borax, as directed under niobates, p. 98, § 1), nearly neutralize the excess of acid with ammonia, add solid ammonium carbonate, shake

vigorously, and allow the liquid to stand for a few minutes. The uranium is at first precipitated, but is soluble in an excess of the ammonium carbonate, and by filtering may be separated from a great many elements which are precipitated by that reagent. Sometimes there is difficulty in obtaining a clear filtrate, and, if so, a few drops of ammonium sulphide may be added with the ammonium carbonate. Make the filtrate containing the uranium acid, boil to expel carbon dioxide, add ammonia in excess, collect the precipitate containing uranium on a filter, and test it with a salt of phosphorus bead. In case the precipitate is small, burn the paper containing it in a crucible, and test the residue.

Vanadium, V.—Usually pentavalent. Atomic weight, 51.4.

OCCURRENCE.—Vanadium is a rare element found in the vanadates, or salts of vanadic acid, H_3VO_4, which is closely related chemically to phosphoric and arsenic acids. Vanadinite, $Pb_4(PbCl)(VO_4)_3$, and descloizite, $Pb(PbOH)VO_4$, are the commonest vanadates.

DETECTION.—1. Vanadium is usually detected by the color it imparts to the fluxes. With borax, in the oxidizing flame, the bead is yellow when hot, changing through yellowish-green to almost colorless when cold. In the reducing flame, it becomes dirty green when hot, changing to fine green when cold. In the salt of phosphorus bead, the color in the oxidizing flame is yellow to deep amber, fading slightly on cooling; while in the reducing flame, it becomes an indistinct dirty green when hot, changing to fine green on cooling. The amber color with salt of phosphorus, in the oxidizing flame, serves to distinguish vanadium from chromium.

2. To detect small quantities of vanadium, and in cases where other substances are present which impart color to the fluxes, proceed as follows: Fuse the powdered mineral in a platinum spoon with about 4 parts of sodium carbonate and 2 of potassium nitrate, and digest the fusion with warm water, in order to dissolve the soluble alkali vanadate. Filter, acidify the filtrate with a slight excess of acetic acid, and add a little lead acetate, which will precipitate a pale yellow lead vanadate (lead chromate, p. 70, § 3, is much yellower). Some of the precipitate collected on a filter-paper may then be tested with a salt of phosphorus bead.

Yttrium, Y.—Trivalent. Atomic weight, 89.

For the reactions of this rare element, see Cerium and the rare earth metals (p. 65).

Zinc, Zn.—Bivalent. Atomic weight, 65.4.

OCCURRENCE.—Zinc occurs most abundantly as sphalerite, ZnS, and in addition to this, smithsonite, $ZnCO_3$; willemite, Zn_2SiO_4;

calamine $(ZnOH)_2SiO_3$; and zincite, ZnO with MnO, occur in sufficient quantities to be mined as ores of the metal. Zinc is also found in a number of other minerals,—franklinite, gahnite, aurichalcite, and in small quantity in many sulphides.

DETECTION.—Zinc volatilizes when heated before the blowpipe, and is usually detected by the coating of oxide on charcoal, and also by the test with cobalt nitrate and the flame coloration.

1. *Reduction of Zinc to the Metallic State and Formation of a Coating of Oxide.*—The best method for the detection of zinc is as follows: Mix the finely powdered mineral with about ½ volume of sodium carbonate, and make into a paste with water. A little of this mixture is then taken up in a small loop on fine platinum wire and heated intensely, holding the loop about 10 mm. from a piece of charcoal, somewhat as represented by Fig. 49. An intense heat and strong reducing action are necessary to bring about reduction to the metallic state and volatilization of the zinc. The metal thus volatilized takes oxygen from the air and collects as a coating of ZnO, which is pale canary-yellow when hot and white when cold. The coating is near where the heat strikes the charcoal, and is not volatile in the oxidizing flame. If the coating is made to deposit on a piece of charcoal previously moistened with cobalt nitrate, the zinc oxide will have a green color which is especially characteristic.

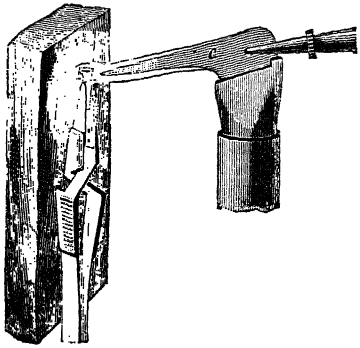

FIG. 49.

For a proper understanding of this test it must be borne in mind that the method demands the reduction of zinc to the metallic state, but no globules form, for, as fast as reduced, the metal volatilizes.

From many compounds, zinc may be reduced, and the coating of oxide obtained without the use of a flux, when a fragment of the mineral (about 2 mm. in diameter) is heated very hot on charcoal in a reducing flame, but some skill in manipulating the flame is needed in order that the fragment shall not be blown away. A good way to make the test is to take the fragment in the platinum forceps, and holding the latter against a piece of charcoal so that the assay is about 5 mm. from the surface, heat at the tip of the blue cone, as shown in Fig. 49.

a. In order to make a zinc oxide coating on charcoal, mix finely powdered calamine, $(Zn.OH)_2SiO_3$, with $\frac{1}{2}$ volume of sodium carbonate, take up in a small loop on platinum wire and heat intensely, as directed. In this experiment the sodium carbonate answers a double purpose: it serves to hold the material on the platinum wire, and also to decompose the silicate, forming sodium silicate, thus setting free zinc oxide, which may be readily reduced. $(Zn.OH)_2SiO_3 + Na_2CO_3 = 2ZnO + Na_2SiO_3 + CO_2 + H_2O$.

b. In order to produce the coating of zinc oxide without the use of a flux, experiment with fragments of smithsonite or sphalerite. With the latter mineral, the oxygen of the air converts ZnS to ZnO, and by the reducing action of the flame, zinc oxide is changed to metallic zinc.

NOTE.—In the presence of lead, bismuth, cadmium, or antimony, which also give coatings of oxide on charcoal, the test for zinc with cobalt nitrate should not be made until the coating has been heated for some time in the oxidizing flame, in order to volatilize the oxides of the metals mentioned.

In the presence of much tin, it is difficult to recognize zinc with certainty by the reaction on charcoal, as tin also gives a white coating of oxide, which when ignited with cobalt nitrate gives a bluish-green color. If, however, the mineral is decomposed by nitric acid (*stannite*), the test may be made as follows: Treat with nitric acid, and separate the tin according to p. 126, § 2, then to the filtrate add solid sodium carbonate until the acid is neutralized, and a permanent precipitate forms, heat to boiling, filter, and wash once with water. The precipitate will contain all the zinc, and probably basic carbonates of other metals, and a portion of it, mixed with sodium carbonate, may be tested on charcoal for zinc.

2. *Flame Test.*—From some minerals, metallic zinc is produced by heating in the platinum forceps in a *strong reducing flame*, and the metal, as it volatilizes and passes into the air, burns with a vivid, pale, bluish-green light, appearing usually as streaks in the outer part of the flame. The experiment does not succeed well when too small a fragment is used, and it is best to take one about 3 mm. in diameter.

Experiments may be made with smithsonite and sphalerite. When the former is used, the zinc carbonate changes readily to oxide, and, by reduction, metallic zinc is slowly formed. With sphalerite, the assay must be first converted by oxidation to zinc oxide, and then by reduction to metallic zinc, but usually a point can be found a little beyond the blue cone of the blowpipe flame, where oxidation and reduction go on simultaneously, and a continuous zinc flame can be maintained.

3. *Heating with Cobalt Nitrate*, $Co(NO_3)_2$.—Some zinc minerals, when moistened with cobalt nitrate and heated, assume a green color, but this simple test can be applied only to infusible, white or light-colored compounds or those which become so on ignition. In making the test, a fragment held in the platinum forceps may be used, but it is usually better to make the finely powdered mineral into a paste with cobalt nitrate, and then to heat on charcoal in an oxidizing flame.

Silicates of zinc, when similarly treated, usually show a blue color, owing to the formation of a fusible cobalt silicate. If an experiment is made with a large fragment of calamine, it will sometimes show blue where the heat was most intense, and green at other parts.

4. *Change of Color upon Heating.*—The presence of zinc is often indicated by the change of color of the assay when heated; i.e., to straw or pale canary-yellow when hot, becoming white when cold. This test can, of course, be applied only to compounds which are white or light-colored.

Zirconium, Zr.—Tetravalent. Atomic weight, 90.7.

OCCURRENCE.—Although a rare element, zirconium is found abundantly in some regions, especially as zircon, $ZrSiO_4$, which, in small quantities, is almost an unfailing constituent in granites and rocks rich in alkalies. It is found in a number of rare minerals, examples of which are baddelyite, ZrO_2, eudialyte, catapleiite, wöhlerite, polymignite, etc.

DETECTION.—Zirconium gives no very characteristic tests which serve for its quick and sure identification. A solution must first be obtained, which usually is accomplished by fusing with sodium carbonate, and treatment as directed under silicates (p. 110, § 4). The decomposition, however, is not complete, and usually only a portion of the zirconium will be obtained in solution. The simplest test is with turmeric-paper, which, when placed in a hydrochloric acid solution containing zirconium, assumes an orange color. As the color is not very marked, it is best to make a comparison by taking two test-tubes, one containing turmeric-paper wet by the solution containing zirconium, and the other a paper wet by acid of about equal strength.

Ammonium, sodium, and potassium hydroxide throw down zirconium hydroxide as a bulky, gelatinous precipitate, insoluble in an excess of sodium and potassium hydroxides, thus differing from aluminium and beryllium. The precipitate is filtered, washed with water, dissolved in a little hydrochloric acid, the solution evaporated until only a drop or two of the acid remains, the residue dissolved in water, and oxalic acid added, when, if zirconium alone is present, either no precipitate forms, or, if it does form, it goes almost immediately into solution (difference from the rare earth metals, cerium, lanthanum, etc., p. 65). A portion of zirconium hydroxide found by the previous test to contain no rare earth metals, or separated from them by means of oxalic acid, may be scraped from the filter-paper, and dissolved in the least possible amount of dilute sulphuric acid ; to the solution, potassium hydroxide is then added until a precipitate forms, afterwards dilute sulphuric acid is added a drop at a time, until the solution clears (if carefully done the liquid at this point will be nearly neutral, and the volume should be small); finally, a little more than an equal volume of a boiling, saturated solution of potassium sulphate is added, which on standing precipitates a double zirconium potassium sulphate as a white powder, and serves as a characteristic test for zirconium, although the precipitation is not complete. If the precipitate is filtered, and washed with a cold and saturated solution of potassium sulphate, then dissolved in warm hydrochloric acid, pure zirconium hydroxide may be precipitated by means of ammonia. On ignition, zirconium hydroxide yields the oxide ZrO_2, and this, if pulverized, mixed with cobalt nitrate, and ignited before the blowpipe on charcoal, assumes a lavender or bluish slate-color.

CHAPTER IV.

TABULATED ARRANGEMENT OF THE MORE IMPORTANT BLOWPIPE AND CHEMICAL REACTIONS.

THIS chapter is intended to be used especially for the interpretation of unknown reactions which are encountered in blowpipe analysis. The tests, if made in the order given below, will serve as a systematic course of *qualitative blowpipe analysis* in examining unknown substances.

A. Heating in the platinum forceps: Flame coloration, p. 135.

B. Heating in the closed tube, p. 137.

C. Heating in the open tube, p. 140.

D. Heating on charcoal, both with and without fluxes, p. 142.

E. Treatment with cobalt nitrate, p. 146.

F. Fusion with the fluxes on platinum wire: Borax, p. 148; phosphorus salt, p. 149; and sodium carbonate beads, p. 151.

G. Treatment with acids, and reactions with the common reagents, p. 151.

A. HEATING IN THE PLATINUM FORCEPS: FLAME COLORATION.

Suggestions concerning the use of the platinum forceps and the methods of heating substances in them have been given in Chapter II, p. 15. In testing minerals, any change which the material undergoes should be carefully noted, but for the identification of the elements, flame colorations are the most important. The colors may often be obtained best by heating on platinum wire, as suggested on p. 35.

If a black, magnetic globule or mass is obtained after heating in the reducing flame, it usually indicates iron, less often cobalt or nickel. If the mass left in the forceps after heating before the blowpipe gives an alkaline reaction when placed on moistened turmeric-paper, it indicates the presence of an alkali or alkaline earth; as *sodium*, *potassium*, *calcium*, *strontium*, *barium*, and possibly *magnesium*.

TABLE OF FLAME COLORATIONS.

Color.	Shade or Tone.	Element.	Remarks.
Red.	Crimson.	Lithium.	The lithia minerals, which are either silicates or phosphates, do not become alkaline after ignition (difference from strontium).
Red.	Crimson.	Strontium.	Carbonates and sulphates show the reaction, and become alkaline after ignition. Silicates and phosphates do not give the strontium flame.
Red.	Yellowish to orange.	Calcium.	Only a few minerals give this color decisively when heated alone. Often, however, the color shows distinctly after moistening the assay with hydrochloric acid.
Yellow.	Intense.	Sodium.	This test is so delicate that great care must be exercised in using it (compare p. 115).
Green.	Yellowish.	Barium.	Carbonates and sulphates show the reaction, and become alkaline after ignition. Silicates and phosphates do not give the barium flame.
Green.	Yellowish.	Molybdenum.	If in the form of oxide or sulphide.
Green.	Bright, somewhat yellowish.	Boron.	The test with turmeric-paper in hydrochloric acid solution is decisive. The compounds rarely show an alkaline reaction after ignition.
Green.	Pure.	Thallium.	
Green.	Emerald.	Copper oxide and iodide.	After moistening the assay with hydrochloric acid, the flame appears azure-blue, tinged with green.
Green.	Pale bluish.	Phosphorus.	The color is not very decisive, but often aids in the identification of a phosphate.
Green.	Bluish.	Zinc.	Appears usually as bright streaks in the flame.
Green.	Pale.	Tellurium. Antimony. Lead.	

TABLE OF FLAME COLORATIONS.—*Continued.*

Color.	Shade or Tone.	Element.	Remarks.
Blue.	Azure.	Copper chloride.	The outer darts of the flame are tinged with emerald-green.
Blue.	Azure.	Selenium.	Accompanied by a characteristic odor.
Blue.	Pale azure.	Lead.	Perceptibly tinged with green in the outer parts.
Blue.		Indium.	
Blue.	Pale.	Arsenic.	
Blue.	Greenish.	Phosphorus. Antimony.	
Violet.	Pale.	Potassium. Rubidium. Caesium.	

B. HEATING IN THE CLOSED TUBE.

Closed tubes and the nature of the reactions which may be obtained in them have been explained on p. 18. The phenomena which are to be especially observed are as follows:

a. Change in the condition or appearance of the assay.

b. The formation of gases which collect in the tube.

c. The formation of sublimates, liquid or solid, which condense on the cold walls of the tube.

a. Change in the Condition or Appearance of the Assay.

1. FUSION.—Only substances which melt very easily, below 1½ in the scale of fusibility, fuse in the closed glass tube.

2. DECREPITATION.—Fragments of decrepitating minerals (compare p. 34) snap and explode, and often break up into very fine powder or dust.

3. PHOSPHORESCENCE AND GLOWING.—Some minerals when heated to a temperature below redness emit a bright, often beautifully colored light, which may continue for a considerable time,

and is seen best in a dark room. A very few minerals *glow*, as if they had taken fire.

4. CHANGE OF COLOR.—Materials often change color after heating, owing to decomposition. Again, without any change in chemical composition, some substances when hot assume colors which are different from those they have when cold. The changes are very numerous, and only a few of the more important are given.

TABLE GIVING CHANGE OF COLOR IN SUBSTANCES WHEN HEATED IN THE CLOSED TUBE.

Original Color.	Color after Heating.		Substance.	Remarks.
	Hot.	Cold.		
Green or blue.	Black.	Black.	Copper minerals.	These changes usually occur when oxides of the metals result from the decomposition due to heating.
Green or brown.	Black.	Black.	Iron minerals.	
Pink.	Black.	Black.	Manganese and cobalt minerals.	
Dark red.	Black.	Dark red.	Ferric oxide.	
White or colorless.	Dark yellow to brown.	Pale yellow to white.	Lead and bismuth minerals.	
White or colorless.	Pale canary-yellow.	White.	Zinc minerals.	

b. The Formation of Gases which Collect in the Closed Tube.

1. CARBON DIOXIDE, CO_2.—Colorless and odorless. May be identified by introducing a drop of barium hydroxide into the tube (p. 64, § 2). Obtained from most carbonates.

2. SULPHUR DIOXIDE, SO_2.—Colorless, with strong, pungent odor. It is further characterized by the acid reaction it imparts to moistened blue litmus-paper. Formed from the decomposition of some sulphates, and in small quantities, also, when sulphides are heated, owing to the air in the tube.

3. OXYGEN, O.—Colorless and odorless, but may be detected as

described on p. 100, § 1. Formed when some higher oxides, especially those of manganese, are heated.

4. AMMONIA, NH_3.—Colorless, with characteristic odor.

5. HYDROFLUORIC ACID, HF.—Colorless, with pungent odor, etching of the glass, and strong acid reaction. From compounds containing fluorine with hydroxyl (p. 77, § 5).

6. NITROGEN DIOXIDE, NO_2.—Red vapors, with pungent odor. From nitrates.

7. BROMINE, Br.—Red vapors, with pungent odor.

8. IODINE, I.—Violet vapors, often accompanied by crystals of iodine.

9. BROWN SMOKE, accompanied by dark distillation products and empyreumatic odor. Organic material.

c. The Formation of Sublimates which Condense on the Walls of the Tube.

TABLE OF SUBLIMATES PRODUCED IN THE CLOSED TUBE.

Color and Condition.		Substance.	Remarks.
Hot.	Cold.		
Colorless liquid; easily volatile.	Colorless liquid.	Water, H_2O.	From all minerals containing water of crystallization and hydroxyl. Neutral if pure, but may be acid from hydrofluoric, sulphuric, and hydrochloric, or other volatile acid. Rarely alkaline from ammonia.
Pale yellow to colorless liquid; difficultly volatile.	Colorless to white globules.	Tellurous oxide, TeO_2.	From tellurium and a few of its compounds.
Red to dark yellow liquid; readily volatile.	Yellow and crystalline solid; nearly white when in small quantity.	Sulphur, S.	From native sulphur and some sulphides (p. 119, § 4).

Continued.

TABLE OF SUBLIMATES PRODUCED IN THE CLOSED TUBE.—*Continued.*

Color and Condition.		Substance.	Remarks.
Hot.	Cold.		
Deep red, almost black liquid; readily volatile.	Reddish-yellow, transparent solid.	Sulphides of arsenic.	From realgar, AsS, orpiment, As_2S_3, and some compounds containing sulphur and arsenic, the sulpharsenites.
Black; difficultly volatile, solid.	Reddish-brown.	Oxysulphide of antimony, Sb_2OS_2.	From sulphide of antimony and some of its compounds with metallic sulphides, the sulphantimonites.
Brilliant black, solid; often gray and crystalline near the heated end.		Arsenic, As.	From native arsenic and some arsenides. If the tube is broken off below the deposit and the arsenic volatilized, the characteristic garlic odor may be obtained.
Brilliant black, solid.		Sulphide of mercury, HgS.	If a little of the sublimate is removed and rubbed very fine, it yields a red powder.
Black fusible globules. The smallest ones transmit a reddish light.		Selenium, Se.	From selenium and some selenides. Usually accompanied by crystals of selenious oxide, SeO_2.
Black fusible globules.		Tellurium, Te.	From tellurium and some tellurides. Usually accompanied by fused globules of tellurous oxide, TeO_2.
Gray metallic globules, which may be united by rubbing with a strip of paper.		Mercury, Hg.	From native mercury and amalgams.
White, solid.		Chlorides of lead and antimony. Oxides of arsenic and antimony. Ammonia salts.	

C. Heating in the Open Tube.

Open tubes, the methods of manipulation, and the nature of the reactions which may be obtained in them, have been explained on p. 18. The phenomena which are to be especially observed are as follows:

a. Odors.

b. The formation of sublimates which condense on the walls of the tube.

c. The character of the residues.

a. Odors.

1. ODOR OF BURNING SULPHUR.—Very strong and pungent, due to oxidation and formation of sulphurous anhydride, SO_2. A piece of moistened, blue litmus-paper placed in the upper end of the tube is reddened, owing to the acid character of SO_2. If properly oxidized, no sublimate of sulphur is formed. The test is exceedingly delicate, and is useful for the identification of sulphides.

2. GARLIC ODOR.—Observed when arsenic is driven off rapidly from its compounds, and is not completely oxidized.

3. ODOR OF SELENIUM.—A peculiar odor, learned only by experience. Obtained when selenium is volatilized from its compounds and not wholly oxidized.

4. ODOR OF OSMIC OXIDE.—Very pungent.

b. Sublimates.

TABLE OF SUBLIMATES PRODUCED IN THE OPEN TUBE.

Color and Character.	Substance.	Remarks.
Black; volatile.	Arsenic and sulphide of mercury.	These sublimates frequently result from too rapid heating of minerals containing arsenic, mercury, antimony, and sulphur, but they will not form if the open-tube test is made properly, with sufficient draft, so that the oxidation is complete.
Brown.	Oxysulphide of antimony.	
Yellow or orange; easily volatile.	Sulphur and sulphides of arsenic.	
Red; volatile.	Selenium, Se.	Often accompanies selenious oxide (see below).
Pale yellow when hot; white when cold.	Molybdenum trioxide, MoO_3.	Forms slowly when molybdenum oxide or sulphide is heated, and collects near the assay as a network of delicate crystals.

Continued.

TABLE OF SUBLIMATES PRODUCED IN THE OPEN TUBE.—*Continued.*

Color and Character.	Substance.	Remarks.
White; readily volatile and crystalline.	Arsenious oxide, As_2O_3.	The sublimate forms as a ring, and where it deposits on the warm glass it is distinctly crystalline (octahedrons).
White; readily volatile and crystalline.	Selenious oxide, SeO_2.	The sublimate usually appears as radiating, prismatic crystals, often accompanied by a little finely divided selenium, which is red.
White to pale yellow globules; slowly volatile.	Tellurous oxide, TeO_2.	
White; slowly volatile and crystalline.	Antimonious oxide, Sb_2O_3.	Obtained from antimony and its compounds, which do not contain sulphur The sublimate consists of two kinds of crystals, octahedrons, resembling As_2O_3, and prisms.
Pale straw-yellow when hot; white when cold; infusible, non-volatile, and amorphous.	Antimonate of antimony, Sb_2O_4.	Obtained from sulphide of antimony and sulphantimonites, as a dense white smoke, which passes up the tube and settles mostly on the under side. This sublimate is usually accompanied by the volatile one of Sb_2O_3.
White; non-volatile and infusible.	Sulphite and sulphate of lead.	Obtained from sulphide of lead as a slight deposit, collecting mostly on the lower side of the tube near the assay.
Gray metallic globules; volatile.	Mercury, Hg.	By rubbing the minute globules with a strip of paper, they may be made to unite.

c. The Character of the Residue.

The residue left after heating in an open tube is usually an oxide, and if saved, it may often be found very useful, especially for treatment with the fluxes on platinum wire or reduction on charcoal.

D. HEATING ON CHARCOAL.

Suggestions concerning the use of charcoal, and the manner in which tests should be made, have been given on p. 39. The phenomena which are to be especially observed are:

a. Odors.

b. Sublimates.

c. The formation of metallic globules or of a magnetic mass, etc.

a. Odors.

1. ODOR OF BURNING SULPHUR.—Obtained by roasting sulphides in the oxidizing flame.

2. ODOR OF GARLIC.—Obtained by heating native arsenic and arsenides in the reducing flame.

3. ODOR OF SELENIUM. — A peculiar odor, which must be learned by experience. Obtained when selenium is volatilized from its compounds in the reducing flame.

b. Sublimates.

TABLE OF SUBLIMATES PRODUCED ON CHARCOAL.

Color and Character.		Substance.	Remarks.
Near the Assay.	Distant from the Assay.		
White; very volatile, and mostly distant from the assay.	White to grayish.	Arsenious oxide, As_2O_3.	Obtained when arsenic, its sulphides, and the arsenides are roasted in the oxidizing flame. Often the garlic odor is pronounced.
Steel-gray; faint metallic luster, and very volatile.	White, frequently tinged with red.	Selenious oxide, SeO_2. The red is Se.	Obtained by roasting selenides in the oxidizing flame. The sublimate when touched with the reducing flame imparts an azure-blue color to the flame. The selenium odor is pronounced.
White; very volatile and mostly distant from the assay.	White and not very pronounced.	Oxide of thallium, Tl_2O.	The sublimate heated in the reducing flame volatilizes, and imparts a green color to the flame.
Dense white; volatile.	Gray, sometimes slightly brownish.	The white is tellurous oxide, TeO_2. The gray is Te.	The sublimate heated in the reducing flame volatilizes, and imparts a green color to the flame.

Continued.

TABLE OF SUBLIMATES PRODUCED ON CHARCOAL.—*Continued.*

Color and Character.		Substance.	Remarks.
Near the Assay.	Distant from the Assay.		
Dense white; volatile, and deposits quite near the assay.	Bluish.	Oxides of antimony, Sb_2O_3 and Sb_2O_4.	Obtained when antimony and its oxides and sulphides are roasted in the oxidizing flame.

White coatings may also result from the volatilization of a variety of compounds, especially chlorides of copper, lead, mercury, ammonium, and the alkalies.

Canary-yellow when hot; white when cold. Not volatile in the oxidizing flame.	Faint white.	Oxide of zinc, ZnO.	By heating some zinc minerals in the reducing flame, metallic zinc is produced, which volatilizes, becomes oxide, and condenses on the coal. If the coating is moistened with cobalt nitrate and ignited, it becomes green.
Faint yellow to white when hot; white when cold. Not volatile in the oxidizing flame.	Faint white.	Oxide of tin, SnO_2.	The coating moistened with cobalt nitrate and ignited assumes a bluish-green color.
Pale yellow when hot; white when cold; sometimes distinctly crystalline. Volatile in the oxidizing flame.	Bluish.	Oxide of molybdenum, MoO_3.	The coating if touched for an instant with the reducing flame assumes a beautiful azure-blue color. A copper-red sublimate of MoO_2 deposits nearer the assay than the MoO_3 coating.
Yellow when hot; straw-yellow when cold. Volatile in both the oxidizing and reducing flames.	Dense white, with bluish-white border.	A mixture of oxide, sulphite, and sulphate of lead.	This sublimate, strongly resembling that of antimony, forms when galena and other sulphides of lead are heated very hot on charcoal.
Dark yellow when hot; sulphur-yellow when cold. Volatile in both the oxidizing and reducing flames.	Bluish-white.	Oxide of lead, PbO.	The coating when moistened with hydriodic acid and heated is changed to volatile, yellowish-green lead iodide.

TABLE OF SUBLIMATES PRODUCED ON CHARCOAL.—*Continued.*

Color and Character.		Substance.	Remarks.
Near the Assay.	Distant from the Assay.		
Dark orange-yellow when hot; orange-yellow when cold. Volatile in both the oxidizing and reducing flames.	Greenish-white.	Oxide of bismuth, Bi_2O_3.	The coating when moistened with hydriodic acid and heated is changed to volatile, chocolate-brown bismuth iodide.
Dark, almost black; changing in short distance to reddish-brown. Volatile in both the oxidizing and reducing flames.	Yellow.	Cadmium oxide, CdO.	When it forms a very thin deposit, the coating often shows an iridescence resembling peacock colors.
Reddish to deep lilac.		Silver when accompanied by lead and antimony.	Pure silver when heated alone on charcoal for a long time gives a slight brownish coating.

c. The Formation of Metallic Globules or of a Magnetic Mass, etc.

In order to obtain metallic globules, the powder is usually mixed with sodium carbonate, and heated in the reducing flame.

1. GOLD.—Rather easily fusible; bright when hot and cold; no coating on the charcoal; color, yellow; malleable.

2. SILVER.—Rather easily fusible; bright when hot and cold; no conspicuous coating on the charcoal; color, white; malleable.

3. COPPER.—Fusible at a rather high heat; bright when in the reducing flame, but oxidizing and becoming black on exposure to the air; no coating on the charcoal; color, red; malleable.

4. LEAD.—Easily fusible; bright when in the reducing flame, but oxidizing on exposure to the air; a yellow coating of oxide of

lead deposits on the charcoal; the metal has a lead-gray color, and is soft and malleable.

5. BISMUTH.—Easily fusible; bright when in the reducing flame, but oxidizing on exposure to the air; a yellow coating of oxide of bismuth deposits on the charcoal; the metal has a lead-gray color, and is brittle, although it may at first flatten to some extent when hammered.

6. TIN.—Easily fusible; bright when in the reducing flame, but oxidizing on exposure to the air; a white coating of oxide of tin deposits on the charcoal if the globule is heated intensely; the metal has a white color, and is soft and malleable.

7. EASILY FUSIBLE GLOBULES with metallic luster, bright when in the reducing flame, but tarnishing on exposure to the air, are frequently obtained when combinations of the metals with sulphur, arsenic, or antimony are heated on charcoal. These globules of sulphide, arsenide, or antimonide of the metals may usually be distinguished from pure metals by their brittleness.

8. MAGNETIC GLOBULES or a magnetic mass will be obtained when substances containing iron, less often cobalt and nickel, are fused with sodium carbonate on charcoal.

9. ALKALINE REACTION.—Provided sodium carbonate has not been used as a flux, a mass or residue, which, after strong ignition, gives an alkaline reaction when placed upon moistened turmeric-paper indicates one of the alkalies or alkaline earths; as *sodium*, *potassium*, *calcium*, *strontium*, *barium*, and possibly *magnesium*.

10. BLACKENS SILVER.—After fusion with sodium carbonate in the reducing flame and placing upon a clean, moistened silver surface, if a black stain is produced, it indicates some compound of sulphur (p. 119, § 5, and p. 122, § 2).

E. TREATMENT WITH COBALT NITRATE.

The method of testing with cobalt nitrate has been given on p. 29. It is applicable only to infusible and light-colored compounds, and is especially useful in detecting zinc and aluminium.

TABLE OF REACTIONS WITH COBALT NITRATE.

Color.	Substance.	Remarks.
Pale pink or flesh-color.	Magnesia, MgO, and salts containing it.	The color is obtained only when very pure compounds are tested, and is not very decisive.
Green; seen best when cold.	Oxide of zinc, ZnO, and compounds containing it.	The test may be applied to fragments of minerals or to the coating of zinc oxide on charcoal.
Bluish-green.	Oxide of tin, SnO_2.	Observed when a coating on charcoal is tested.
Ultramarine-blue.	Aluminium oxide, Al_2O_3, and compounds containing it.	About the best test for aluminium, but must not be mistaken for silicate of zinc.
Ultramarine-blue.	Silicates of zinc.	Due to a fusible silicate of cobalt.
Dirty green.	Oxide of antimony.	These colors are rather indistinct, and not very satisfactory.
Yellowish-green.	Oxide of titanium.	
Violet.	Oxide of silicon, quartz.	
Lavender.	Oxide of beryllium.	

F. FUSION WITH THE FLUXES ON PLATINUM WIRE.

These tests may be divided into three heads as follows:

a. Fusion with borax.
b. Fusion with salt of phosphorus.
c. Fusion with sodium carbonate.

It should be borne in mind that the colors given in the following tables are those which the *pure oxides* of the metals yield when dissolved in the fluxes, but it would be almost impossible to tabulate all the varieties of color given by mixtures of the oxides. If a substance which is to be tested is not an oxide, it may be frequently brought into that condition by roasting on charcoal or in an open tube.

Too much pains cannot be taken in making the beads of suitable size, about 3 mm. in diameter, introducing the proper amount of material into them, and heating successfully both in the oxidizing and reducing flames. Suggestions about making beads and fusing substances in them have been given on pp. 16, 24, and 25.

a. Fusion with BORAX *on Platinum Wire.*

TABLE OF REACTIONS OBTAINED WITH BORAX.

Oxidizing Flame.		Amount of Material.	Produced by	Reducing Flame.	
Hot.	Cold.			Hot.	Cold.
Colorless.	Colorless.	Little or much.	Oxides of silicon, aluminium, and tin.	Colorless.	Colorless.
Colorless.	Colorless or opaque white, depending upon the degree of saturation.	Little or much.	Oxides of calcium, strontium, barium, magnesium, beryllium, zinc, yttrium, lanthanum, thorium, zirconium, tantalum, and columbium.	Colorless.	Colorless or opaque white, depending upon the degree of saturation.
Pale yellow.	Colorless or white.	Much.	Oxides of lead, antimony, and cadmium.	Pale yellow.	Colorless.
Pale yellow.	Colorless or white.	Much.	Oxide of bismuth.	Gray.	Gray.
Pale yellow.	Colorless or white.	Much.	Oxide of molybdenum.	Brown.	Brown.
Pale yellow.	Colorless or white.	Medium.	Oxide of tungsten.	Yellow.	Yellow to yellowish brown.
Pale yellow.	Colorless or white.	Medium.	Oxide of titanium.	Grayish.	Brownish-violet.
Yellow.	Nearly colorless.	Little.	Oxides of iron and uranium.	Pale green.	Nearly colorless.
Yellow.	Pale yellow.	Little.	Oxide of cerium.	Colorless.	Colorless.
Yellow.	Yellowish-green.	Little.	Oxide of chromium.	Green.	Green.
Yellow.	Yellowish-green, almost colorless.	Little.	Oxide of vanadium.	Dirty green.	Fine green.
Deep yellow to orange-red.	Yellow.	Medium to much.	Oxide of cerium.	Colorless.	Colorless.
Deep yellow to orange-red.	Yellow.	Medium to much.	Oxide of uranium.	Pale green.	Pale green to nearly colorless.

TABLE OF REACTIONS OBTAINED WITH BORAX.—*Continued.*

Oxidizing Flame.		Amount of Material.	Produced by	Reducing Flame.	
Hot.	Cold.			Hot.	Cold.
Deep yellow to orange-red.	Yellow.	Medium to much.	Oxide of iron.	Bottle-green.	Pale bottle-green.
Deep yellow to orange-red.	Yellowish-green.	Medium to much.	Oxide of chromium.	Green.	Green.
Green.	Blue.	Little to medium.	Oxide of copper.	Colorless to green.	Opaque red with much oxide.
Green.	Yellow, green, or blue, of various shades.	Medium.	Various mixtures of the oxides of iron, copper, nickel, and cobalt.	(?)	(?)
Blue.	Blue.	Little to medium.	Oxide of cobalt.	Blue.	Blue.
Violet.	Reddish-brown.	Little to medium.	Oxide of nickel.	Opaque gray.	Opaque gray.
Violet.	Reddish-violet.	Little.	Oxide of manganese.	Colorless.	Colorless.
Pale rose.	Pale rose.	Much.	Oxide of didymium.	Pale rose.	Pale rose.

b. Fusion with PHOSPHORUS SALT *on Platinum Wire.*

TABLE OF REACTIONS OBTAINED WITH PHOSPHORUS SALT.

Oxidizing Flame.		Amount of Material.	Produced by	Reducing Flame.	
Hot.	Cold.			Hot.	Cold.
Colorless.	Colorless, but when strongly saturated the beads may in some cases appear opaque white.	Little or much.	Oxides of calcium strontium, barium, magnesium, beryllium, zinc, aluminium, yttrium, lanthanum, thorium, zirconium, tin, and silicon, the latter almost insoluble.	Colorless.	Colorless, but when strongly saturated the beads may in some cases appear opaque white.

Continued.

TABLE OF REACTIONS OBTAINED WITH PHOSPHORUS SALT.—*Cont'd.*

Oxidizing Flame.		Amount of Material.	Produced by	Reducing Flame.	
Hot.	Cold.			Hot.	Cold.
Very pale yellow.	Colorless.	Much.	Oxides of tantalum and cadmium.	Very pale yellow.	Colorless.
Very pale yellow.	Colorless.	Much.	Oxides of lead, antimony, and bismuth.	Gray.	Gray.
Very pale yellow.	Colorless.	Much.	Oxide of niobium.	Brown.	Brown.
Pale yellow.	Colorless.	Medium.	Oxide of tungsten.	Dirty blue.	Fine blue.
Pale yellow.	Colorless.	Little to medium.	Oxide of titanium.	Yellow.	Violet.
Yellow.	Colorless.	Medium.	Oxide of cerium.	Colorless.	Colorless.
Yellow.	Colorless.	Little.	Oxide of iron.	Very pale yellowish-green.	Colorless.
Yellow.	Pale greenish-yellow.	Medium.	Oxide of uranium.	Pale dirty green.	Fine green.
Yellowish-green.	Colorless.	Medium.	Oxide of molybdenum.	Dirty green.	Fine green.
Deep yellow to brownish-red.	Yellow to almost colorless.	Medium to much.	Oxide of iron.	Red, yellow, to yellowish-green.	Almost colorless to very pale violet.
Yellow to deep yellow.	Yellow.	Little to medium.	Oxide of vanadium.	Dirty green.	Fine green.
Reddish to brownish-red.	Yellow to reddish-yellow.	Little to medium.	Oxide of nickel.	Reddish to brownish-red.	Yellow to reddish-yellow.
Green.	Rather pale blue.	Little.	Oxide of copper.	Pale yellowish-green.	Pale blue, nearly colorless; at times ruby-red.
Dark green.	Blue.	Medium.	Oxide of copper.	Brownish-green.	Opaque red.
Green.	Yellow, green, or blue, of various shades.	Medium.	Various mixtures of the oxides of iron, copper, cobalt, and nickel.	?	?

TABLE OF REACTIONS OBTAINED WITH PHOSPHORUS SALT.—*Cont'd.*

Oxidizing Flame.		Amount of Material.	Produced by	Reducing Flame.	
Hot.	Cold			Hot.	Cold.
Dirty green.	Fine green.	Little to medium.	Oxide of chromium.	Dirty green.	Fine green.
Blue.	Blue.	Little to medium.	Oxide of cobalt.	Blue.	Blue.
Grayish-violet.	Violet.	Medium.	Oxide of manganese.	Colorless.	Colorless.
Pale rose.	Pale rose.	Much.	Oxide of didymium.	Pale rose.	Pale rose.

c. *Fusion with* SODIUM CARBONATE *on Platinum Wire.*

If heated in the oxidizing flame, an opaque bead, green when hot, blue when cold, indicates manganese. The color disappears in the reducing flame.

A yellow bead in the oxidizing flame indicates chromium.

A clear glass can be made by fusing with a sufficient quantity of silica.

G. TREATMENT WITH ACIDS, AND REACTIONS WITH THE COMMON REAGENTS.

As a general rule, it may be recommended to treat 1 or 2 ivory spoonfuls of the finely powdered mineral in a test-tube with about 5 cc. of acid; heat to boiling, and observe any changes which take place. For minerals without metallic luster, hydrochloric acid is usually the most convenient solvent, while for the sulphides and arsenides, which usually have metallic luster, nitric acid is best. The following should be especially observed:

a. *Evolution of Gases.*

1. CARBON DIOXIDE, CO_2.—Colorless and odorless. Obtained from all carbonates (p. 62, § 1).

2. Hydrogen Sulphide, H_2S.—Colorless, with disagreeable odor. Obtained from sulphides (p. 121, § 7).

3. Chlorine, Cl.—Nearly colorless, with disagreeable odor. Obtained from a few higher oxides when dissolved in hydrochloric acid (p. 101, § 2).

4. Nitrogen Dioxide, NO_2.—Dark red vapors derived from nitric acid when oxidation is taking place (p. 120, § 6).

b. Color of the Solution.

A great variety of colors may be obtained, but only the common ones will be mentioned.

1. Amber to Brownish-Red.—Hydrochloric acid solutions containing ferric iron.

2. Green.—From mixtures of copper and iron, and also from nickel. Addition of ammonia in excess gives a blue color with copper and nickel, the former being more intense.

3. Blue.—From copper, and greatly intensified by adding an excess of ammonia.

4. Pink or Pale Rose.—From cobalt.

c. Insoluble Residue after Decomposing a Mineral.

1. A Jelly.—When this is obtained by evaporation of a solution, and is insoluble upon subsequent addition of water or acid, it indicates a silicate (p. 108, § 1).

2. A Pulverulent Residue.—White, but more transparent in the acid than the original powdered mineral; it may indicate a silicate (p. 109, § 2).

3. White Residues.—These may be obtained when minerals containing tin, antimony, and sulphide of lead are oxidized by nitric acid.

4. A Yellow Residue.—This may indicate tungsten. A spongy mass or fused globule of sulphur is also often obtained when sulphides are treated with nitric acid (p. 120, § 6).

d. Precipitation by Adding Appropriate Reagents to the Clear Solution.

Only those reagents which are most useful in making simple test-tube experiments will be mentioned.

1. AMMONIA precipitates aluminium, beryllium, bismuth, chromium (trivalent), iron (ferric), lead, and the rare earth metals (p. 65), as hydroxides.

Under a variety of conditions, especially when phosphoric, arsenic, silicic, and hydrofluoric acids are present, many other elements may be precipitated ; e.g., calcium phosphate is precipitated when ammonia is added to an acid solution of apatite (p. 60, § 4, *b*).

2. AMMONIUM CARBONATE is especially convenient for precipitating calcium, strontium, and barium carbonates from solutions made alkaline by ammonia.

3. AMMONIUM OXALATE is useful for the precipitation of calcium oxalate from solutions made alkaline by ammonia. Barium and strontium are also precipitated.

4. AMMONIUM SULPHIDE precipitates, from solutions which are nearly neutral or alkaline, iron, zinc, manganese, cobalt, and nickel, as sulphides, and aluminium, chromium, and the rare earth metals, as hydroxides. It is also useful for dissolving freshly precipitated sulphides of arsenic, antimony, and tin.

5. BARIUM CHLORIDE precipitates barium sulphate from acid solutions, and serves, therefore, as a very delicate test for a sulphate.

6. HYDROCHLORIC ACID precipitates silver, lead, and mercurous chlorides from nitric acid solutions.

7. HYDROGEN SULPHIDE gas, when led into hydrochloric or sulphuric acid solutions, precipitates silver, lead, mercury, copper, bismuth, cadmium, arsenic, antimony, and tin, as sulphides. If the solution is in nitric acid, it is best to evaporate in a casserole with sulphuric acid, until the nitric acid is expelled, and then, after dissolving in water, to run in the hydrogen sulphide gas.

8. SILVER NITRATE precipitates silver chloride, bromide, or iodide from solutions of chlorides, bromides, or iodides, in water or dilute nitric acid.

9. SODIUM CARBONATE precipitates iron, zinc, manganese, cobalt, nickel, copper, magnesium, and many other metals, as basic or normal carbonates.

10. SODIUM HYDROXIDE precipitates iron, manganese, cobalt, nickel, copper, bismuth, cadmium, magnesium, and the rare earth metals, as hydroxides, some of these only in the absence of ammonium salts.

11. SODIUM PHOSPHATE is useful for detecting magnesium in solutions which are not precipitated by ammonia and ammonium carbonate, or have been filtered from the precipitates produced by these reagents.

12. SULPHURIC ACID precipitates lead, barium, strontium, and calcium sulphates, the last, however, only when the solutions are concentrated.

CHAPTER V.

PHYSICAL PROPERTIES OF MINERALS.

IN the foregoing chapters, minerals have been regarded from the standpoint of their chemical composition only, but they possess in addition certain *physical properties* which may be very useful for their identification and recognition. The most important of these are crystallization, luster, color, hardness, fusibility, and specific gravity.

CRYSTALLOGRAPHY.*

Crystallization. — When a mineral or chemical compound assumes a solid form, it does so by separation from a solution, or from a molten mass, or by condensation from a vapor; and the molecules, or smallest particles of the substance, generally assume a definite arrangement. This process is called *crystallization*, and when it takes place under favorable circumstances it gives rise to *crystals*, or solids which have not only *definite internal structure or arrangement of the molecules*, but also *definite shapes* bounded by flat surfaces.

Very little is known concerning the molecules which form crystals: they may correspond to the chemical molecules, but are probably larger, and aggregates of them; and certainly in all instances they are *excessively minute.* It is a very important property of crystals that, during their growth, the molecules of the substance tend to arrange or group about themselves *only those of*

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* Owing to limited space, this important subject will have to be treated in a somewhat elementary manner, but it is hoped that the essential features can be presented with sufficient clearness to enable the student to become familiar with the more important, simple, crystalline forms and combinations. To obtain a really satisfactory knowledge of the subject it is quite essential to supplement the text by a collection of crystals or models.

the same kind. The crystallized condition of a compound is, therefore, one of the very best proofs of its *homogeneous character and purity.*

That solids with plane surfaces may result from the arrangement of particles of the same kind is shown by Fig. 50, which represents geometrical shapes made by a regular arrangement of shot. If the shot were so exceedingly small that the individual ones could not be seen, the outer surfaces of the solids would appear perfectly smooth and flat. Such an arrangement is, however, somewhat misleading, since the shot are in contact with one another, while in crystals the distances between the molecules are probably considerably greater than the diameters of the molecules themselves. A more correct idea, therefore, of an arrangement of molecules in a crystal may be gained from Fig. 51. In a crystal the molecules are all of the same kind, and in any given direction they must be equally distant from one another.

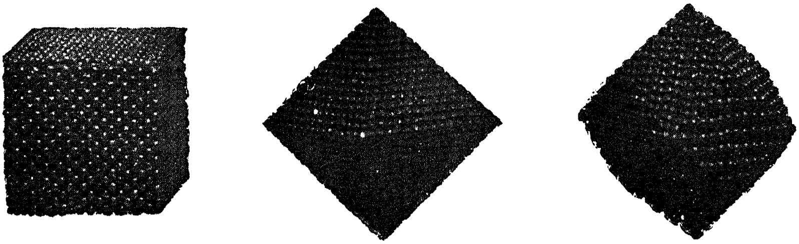

FIG. 50.

Cube, octahedron, and dodecahedron made by the regular arrangement of shot. The arrangement of the shot is identical in the three models, but different layers of shot constitute the outer or limiting surfaces.

As in an orchard where the trees are evenly spaced one may look in different directions, *ab*, *ac*, *af*, etc., (Fig. 52), and see the trees in rows, so through a regular arrangement of particles, as in Fig. 51, there are certain definite directions in which the particles lie in planes. The crystal faces correspond to molecular planes, and have definite inclinations or angles, depending upon the molecular arrangement.

Provided a crystal has not been hindered in its development it will be bounded by flat surfaces, which give it a regular external form, and this is one of its most striking features. It is only occasionally, however, that a crystal develops without interruption, for it usually is interfered with by others, or grows against some obstacle so that only a portion or perhaps nothing of its characteristic external form is produced. *Even when the external form is wholly wanting, the crystalline nature of a substance, due to the regular arrangement of the molecules, may be revealed by some of the physical properties peculiar to crystals.* Thus by the aid of polarized light it could instantly be told that a transparent fragment of quartz possessed a crystalline structure and was not a bit of glass.

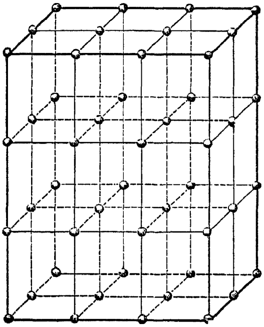

FIG. 51.

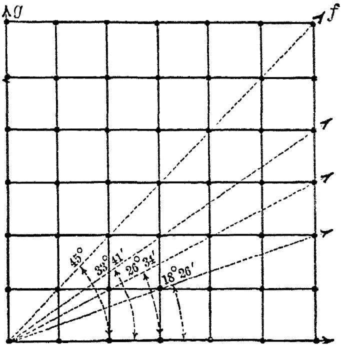

FIG. 52.

Most minerals have been observed in a crystallized condition, and it is important to bear in mind that *only definite chemical compounds* possess this peculiar property of crystallization.

Constancy of the Interfacial Angles of Crystals. — One of the most important features of crystals is that those of the same substance *invariably exhibit the same angles between similar faces.* It is evident that in an orchard one must look in definite directions, *ab*, *af*, *ag*, etc. (Fig. 52), to see the trees in rows, these directions depending upon the way in which the trees are planted. In Fig. 52 the trees are represented as equally spaced along the rows *ab* and *ag*, with these rows at right angles to one another. It must also follow that constancy of interfacial angles is a feature of crystals, provided each substance has its own definite molecular structure (Fig. 51), and that the faces correspond to layers of molecules.

Goniometers.—Instruments for measuring the interfacial angles of crystals are called goniometers.

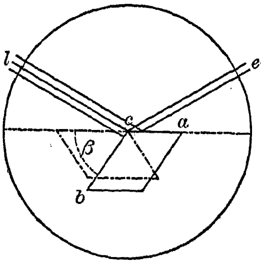

FIG. 53.

The *reflection goniometer* consists of a divided circle turning upon an axis, and provided with devices for holding and adjusting crystals so that the edge between the faces to be measured can be made to coincide with, and be paralled to, the axis of the instrument. Rays of light *l* (Fig. 53), either coming from a distant object, or made parallel by passing through a lens, fall upon the face *ac* of a crystal, and some of them are reflected in the direction of the observer *ce*. It is evident that in order to obtain a reflection in a similar direction from the face *cb*, it will be necessary to turn the crystal through the angle *β*, which is the supplement of the angle *acb*, the angles being read from a divided circle. Measurements can thus be made with great accuracy even on very small crystals. In studying and calculating the mathematical relations of crystal faces, the ~~*supplement*~~ *angles* are much more convenient to use than the actual ones, and are almost invariably employed by crystallographers.

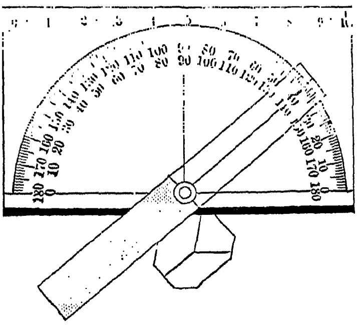

FIG. 54. (About ½ natural size).

An inexpensive *contact goniometer*, designed by the author, consists of a graduated semicircle (Fig. 54) printed on cardboard, and provided with a measuring arm of transparent celluloid which is swiveled by means of an eyelet exactly in the center of the arc. A fine line, scratched on the under surface of the celluloid arm and blackened, and in exact alinement with the center of the eyelet, serves to indicate the angle. In using the instrument the edges of the card and measuring arm are brought as nearly as possible in contact with the crystal faces, care being taken that the plane of the card is held at right angles to the edge formed by the intersection of the crystal faces.

Crystallographic Axes.—In order to show the relations of crystal faces it is convenient to take certain directions within the crystals as *axes*. Usually three are chosen (Fig. 55), one *a* -*a*, going from front to back, another *b* -*b*, from right to left, and a third *c* -*c*, vertical. Positive and negative directions are assumed from the center, as indicated in the figure. Crystal faces intersect these axes, and, by measuring appropriate interfacial angles, the *relative lengths* of the axes, or their *ratio* to one another, can be determined. For example, sulphur crystals have the form of a pyramid (Fig. 56), and the angles which are measured over the edges joining the *a* and *b*, and the *b* and *c* axes, respectively, equal 36° 40½′ and 94° 52′. From these angles it can be calculated, by simple mathematical processes, that, if the length *ob* is assumed as *unity*, the lengths *oa* and *oc* are 0.813 and 1.903, respectively. Designating the lengths of the axes *oa*, *ob*, and *oc* as *a*, *b*, and *c*, the foregoing mathematical relation can be expressed as follows: $a : b : c = 0.813 : 1 : 1.903$. This is known as the *axial ratio* of sulphur.

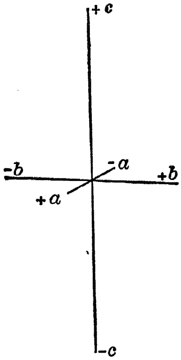

FIG. 55.

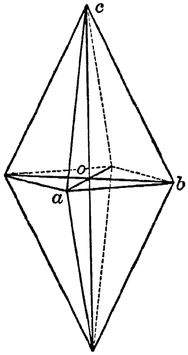

FIG. 56.

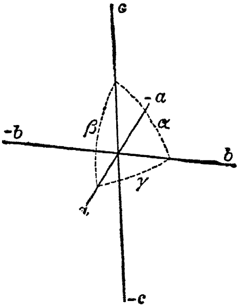

FIG. 57.

When the axes are not at right angles to one another the angles α, β, and γ (Fig. 57) must be determined.

Parameters.—Parameters are the distances from the center o (Fig. 56), at which crystal faces intersect the axes. For example, oa, ob, and oc are the parameters of the face abc. If oa, ob, and oc correspond to the characteristic lengths of the respective axes of any mineral, the face in question is then said to have the parameters $a : b : c$.

It must be distinctly borne in mind that the parameter distances oa, ob, and oc, or the axial lengths, are not expressed in terms of any unit of measure, but have only *relative values*. For example, no matter what length is chosen for the b axis, if a and c have relatively the lengths that have been determined for sulphur, $a : b : c = 0.813 : 1 : 1.903$, then the eight plane surfaces which intersect the extremities of the a, b, and c axes will form a pyramid (Fig. 56) whose interfacial angles will be like those of a sulphur crystal.

Law of Definite Mathematical Ratio.—It is a very important feature of crystals that their faces, prolonged if necessary, will intersect the axes *only at the ratio distances* a, b, and c, characteristic of each substance, or at *simple multiples, or fractions*, of these ratio distances. A plane may, however, be parallel to one or two of the axes, which is indicated by the sign of infinity. Given the axes a $-a$, b $-b$, and c $-c$ (Fig. 58) of the ratio lengths characteristic for any substance, then possible crystal faces might have the parameter relations $a : b : c$, $2a : b : c$, $a : b : \frac{1}{2}c$, etc., or $\infty a : b : c$, $\infty a : \infty b : c$, etc. Experience has shown, moreover, that the multiples at which the *characteristic axial lengths* are cut, are most often *unity* (not expressed before the letters) and *infinity*, or such simple quantities as 2, 3, ½, or ⅓. When no sign is expressed, a positive one is always understood.

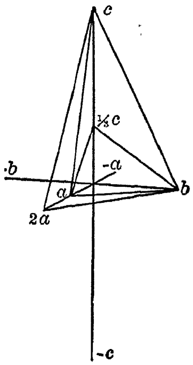

Fig. 58.

As a further illustration of this *very important principle*, suppose three wires are fastened together at right angles to one another, and cut off so that their relative lengths shall correspond to the crystallographic axes of sulphur, $a:b:c = 0.813:1:1.903$ (Fig. 59), then the eight planes joining the extremities of the a, b, and c axes, and another set of eight planes going from the extremities of the a and b axes to $\frac{1}{3}$ on the c axis, *would have the direction, or make with one another, the characteristic angles* of the faces p and s (Fig. 60) which occur on crystals of sulphur. It will be observed from a consideration of Figs. 59 and 60 that the faces p, having their origin at a and b, do not intersect the vertical axis, but, if *extended*, would do so at c. Also, the faces s, having their origin at a certain distance on the vertical axis, when extended would intersect the horizontal axes at points beyond a and b. The *relative distances*, however, at which the three axes are cut by the s faces are the same as those of the planes indicated by dotted lines in Fig. 59, going from $a:b:\frac{1}{3}c$, for the s faces are parallel to these.

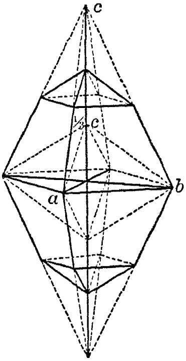

FIG. 59.

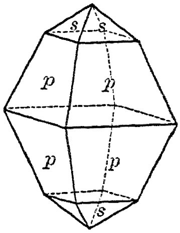

FIG. 60.

It must be distinctly borne in mind that parameter relations furnish a means of expressing the *directions* of crystal faces when they are referred to axes of known lengths and position, but they in no way affect the size of the faces. A crystal face may be regarded as shifted to any extent, provided it is kept *parallel to its original position*, without in the least affecting the *relative distances* at which the axes are intersected.

Indices.—The position and direction of crystal faces with reference to axes can also be expressed by numbers, known as *indices*, which are the *reciprocals* of the parameters. The reciprocal of a number is one divided by the number, $\frac{1}{\infty} = 0$. Indices are written as *whole numbers*, the reciprocal values being cleared of fractions when necessary, and the minus sign, when needed, is written over the number.

The following examples will serve to illustrate the relations of parameters and indices:

Parameters.	Indices.	Parameters.	Indices.
$a : b : c$	111	$2a : b : c$	122
$a : b : \infty c$	110	$a : -\frac{3}{2}b : 3c$	$3\bar{2}1$
$\infty a : \infty b : -c$	$00\bar{1}$	$-a : b : \frac{1}{3}c$	$\bar{1}13$

If one will keep in mind the reciprocal relation existing between indices and parameters, it soon becomes an easy matter to use indices, and to conceive of the position and direction of crystal faces expressed by them. For example, $00\bar{1}$ designates a plane parallel to the a and b axes, and intersecting the negative end of c. The indices 122 (read *one*, *two*, *two*) designate a face intersecting a, $\frac{1}{2}b$, and $\frac{1}{2}c$; such a plane is parallel to, and, therefore, crystallographically identical with, a plane expressed by the parameter relation $2a : b : c$ (Fig. 61). The indices $3\bar{2}1$ designate a face intersecting $\frac{1}{3}a$, $-\frac{1}{2}b$, and c, which is parallel to the face having the parameter relation $a : -\frac{3}{2}b : 3c$ (Fig. 62).

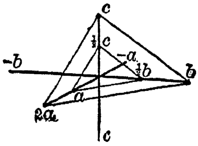

FIG. 61.

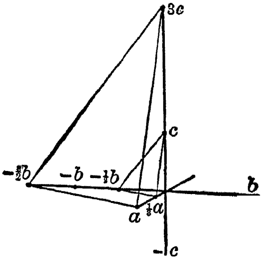

FIG. 62.

It is important to note the order in which the indices are written, the first, second, and third numbers referring *invariably* to the characteristic a, b, and c axes.

Since indices furnish a very convenient method of expressing crystallographic relations, they have been almost universally adopted by crystallographers.

Symmetry.—Upon examining crystals it will be observed that there is a certain regularity in the recurrence of faces and angles of the same kind, which is designated as *symmetry*. The symmetry of crystals is expressed in terms of imaginary planes and axes passing through them.

Symmetry Plane.—A plane is called a *symmetry plane* when it divides a crystal in such a manner that the faces and angles on one side of the plane are repeated on the side *directly opposite.* Thus in Fig. 63 of orthoclase, the shaded plane divides the figure *symmetrically.* A symmetry plane is of such a nature that, if a crystal is held before a mirror with the symmetry plane parallel to the reflecting surface, the crystal and its reflection present the same appearance.

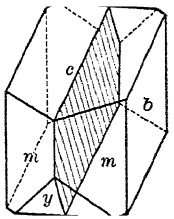

FIG. 63.

Symmetry Axis.—When a crystal, on being revolved, shows a recurrence of similar faces and angles, the direction about which the revolution has taken place is called an axis of symmetry. In Fig. 63 the direction at right angles to the face *b* is an axis of symmetry; by a turning of 180° about this axis, the crystal would occupy the same position in space, and therefore present the same appearance. The symmetry of crystals as referred to axes is of four kinds: *binary, trigonal, tetragonal,* and *hexagonal,* according as the recurrence of similar parts or features takes place *two, three, four,* or *six times* during a revolution of 360°, and the four kinds are indicated by the following signs: ⬬▲◆⬢.

Crystallographic axes, (page 159) correspond to axes of symmetry whenever it is possible to make them.

Center of Symmetry.—A crystal is said to have a center of symmetry when it is so developed that for every face there is a possible one of exactly similar character, diametrically disposed with reference to a central point.

The Crystal Form.—All of the faces of the *same kind* which are possible on a crystal of given symmetry constitute a *crystal form.* For example, take the axes of binary symmetry, *a*–*a*, *b* –*b*, and *c* –*c* (Fig. 64), which are of unequal lengths and at right angles to one another, and assume that there are three planes of symmetry, each passing through two of the axes; the eight faces intercepting the extremities of the axes would then *be alike* and would produce a *form* known as a pyramid. In giving the symbol of such a form it is customary to give the parameters $a : b : c$, or indices (111) of only one of the faces, since the number of possible faces of the same kind can readily be told, *provided the symmetry is known.*

In Fig. 63, which represents an orthoclase crystal with one axis of binary symmetry and one plane of symmetry, there are three *forms*, *b*, *c*, and *y*, each consisting of two faces, and a fourth *form m*, having four faces.

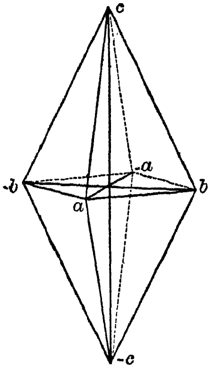

Fig. 64.

Normal or Holohedral Forms.—Fig. 64 represents the most symmetrical arrangement of the crystal faces about the axes *a* -*a*, *b* -*b*, and *c* -*c*. Eight faces of the same kind are possible, all of which are developed, and the term *normal form* will be used for designating crystals of this character. It is also customary to designate such a form as *holohedral* (ὅλος, whole, and ἕδρα, face).

Hemihedrism.—About a system of three, unequal axes, at right angles to one another, it is possible to have forms with a lower degree of symmetry than that of the pyramid (Fig. 64). For example, provided the axes are symmetry axes, and that there are *no planes of symmetry*, the *form* $a : b : c$ (111) would then consist of four faces (Fig. 65). Such a form is often designated as *hemihedral* (ἡμι, half, and ἕδρα, face), since it has only half as many faces as are possible when the highest degree of symmetry prevails.

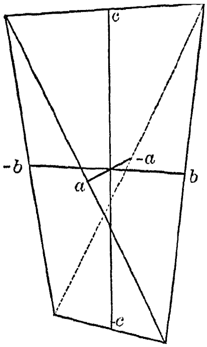

Fig. 65.

Hemimorphism.—This term is applied to the property, exhibited by some minerals, of having *different crystalline forms* at opposite extremities of an axis of symmetry. Thus, a crystal of calamine (Fig. 66) shows the forms lettered *c*, *t*, and *i* above, which are different from *v* below. Crystals of tourmaline (Figs. 67 and 68) have very different forms at the upper and lower extremities of the vertical axis. Hemimorphic crystals show marked pyroelectricity, see p. 231.

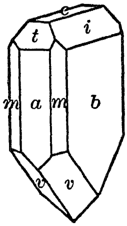

FIG. 66.

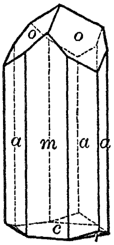

FIG. 67.

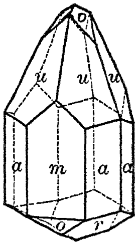

FIG. 68.

Crystal Habit.—It is characteristic of every substance that its crystals possess *a certain kind of symmetry*, or belong to a certain *system of crystallization*, although their forms or *habit* may be very different. Thus Figs. 69, 70, and 71 illustrate the forms of the cube, octahedron, and dodecahedron, which may be observed in fluorite. The shot models (Fig. 50, p. 156) also show these three forms, and will perhaps serve to explain why it is that there can be a difference in habit. The forms of the models depend upon the *directions* of the layers of shot which represent the outer or limiting surfaces, while the arrangement of the shot with reference to one another is the same in all three models. As explained on p. 155, each chemical substance possesses a *definite arrangement* of its crystal molecules, but layers of molecules having different directions may constitute the crystal faces.

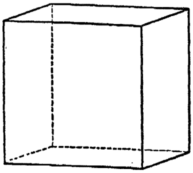

FIG. 69.

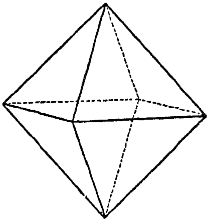

FIG. 70.

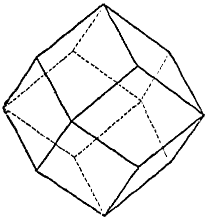

FIG. 71.

Distorted Crystals.—It generally happens that during the growth of crystals material is supplied more abundantly to some parts than to others, and consequently they do not attain an ideally symmetrical development. For example, although pyrite crystallizes in cubes (Fig. 72), it is frequently found in forms having some faces larger than others (Figs. 73 and 74). These forms, although departing from the type of a geometrical cube, are considered, crystallographically, as *distorted cubes,* since each interfacial angle equals 90°, and all the faces have similar physical properties. Fig. 75 represents a symmetrical octahedron and Fig. 76, a *distorted* one; Fig. 77, a symmetrically developed quartz crystal, and Fig. 78, a *distorted* one with the corresponding faces *m*, *r*, and *z* differently developed.

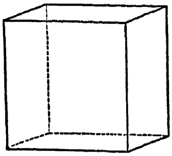
FIG. 72.

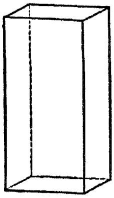
FIG. 73.

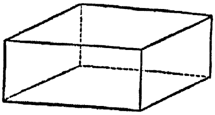
FIG. 74.

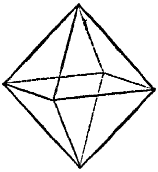
FIG. 75.

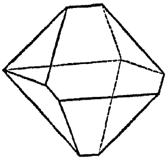
FIG. 76.

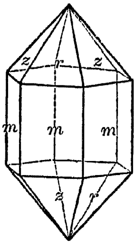

FIG. 77.

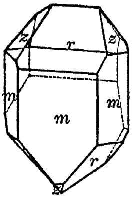

FIG. 78.

Distorted crystals are the rule rather than the exception, although the distortion is not usually so great as represented by the foregoing illustrations. Moreover, it should be clearly understood that the characteristic interfacial angles of crystals are in no way affected by inequalities in the size of similar faces.

Crystal Combinations.—The occurrence of two or more different forms, or dissimilar kinds of faces, on a single crystal is called a *combination.* Fig. 60 (p. 161) illustrates the way the forms *p* and *s* combine on a crystal of sulphur, and Fig. 63 (p. 163), a combination of the four forms *b*, *c*, *y*, and *m* on a crystal of orthoclase. Farther on, when the systems of crystallization are described, this important subject of crystal combinations will be more fully illustrated and explained.

Truncations.—When an edge which would be formed by the meeting of two crystal faces is replaced by a plane, that edge is said to be *truncated.* Fig. 79 represents a cube *a* whose edges are truncated by the planes *d.* The term truncation is generally used in a restricted sense, to denote that truncating planes make equal angles with the adjacent faces. When the angles on adjacent faces are unequal the term *oblique truncation* is used.

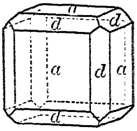

FIG. 79.

A solid angle is said to be *truncated* when it is replaced by a plane. Fig. 80 represents a cube *a* whose solid angles are truncated by the planes *o.*

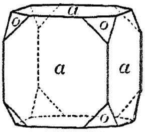

FIG. 80.

Twin Crystals.—When crystals grow together in other than a parallel position, so that they have a *certain crystallographic plane, or direction, in common,* they are known as *twin crystals.* These generally present the appearance of two halves of a crystal (Fig. 81) united by a plane called the *twinning-plane,* and are known as *contact twins.* Twin crystals of this type are of such a nature that the form of a simple crystal would result if the twins were cut in two along the twinning-plane, and either one of the halves should be revolved 180° about an axis which is at right angles to the twinning-plane. Such an axis is known as the *twinning-axis.* For example, if the lower half of the twin crystal rep-

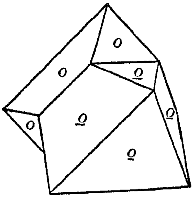

FIG. 81.

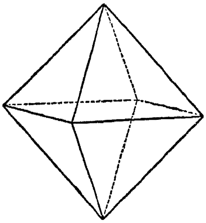

FIG. 82.

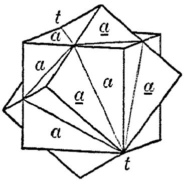

FIG. 83.

resented in Fig. 81 was thus revolved, an octahedron (Fig. 82) would result; hence such a crystal is called a *twinned octahedron.*

Two individuals may also appear as penetrating through one another (Fig. 83) and such are known as *penetration twins.* In this type of twins one of the individuals is brought into the same position as the other by a revolution of 180° about the twinning-axis. For example, the cube $\underline{a}$ if thus revolved about the twinning-axis $t\ t$ would assume the position of the cube a.

A twinning-plane can *never* be a symmetry-plane, and is almost invariably parallel to a face having a simple relation to the crystallographic axes.

Fig. 84 represents a simple crystal of aragonite; Fig. 85, a twin in which one of the m faces is the twinning-plane; and Fig. 86, a *repeated twinning*, in which the parts I and III are in a parallel position, and have between them a lamella II in twin position. When there are a series of lamellæ in twin position the twinning is said to be *polysynthetic.* Fig. 87 represents a piece of oligoclase feldspar where the polysynthetic twinning has given rise to a surface which appears distinctly striated, and consists of a series of alternating re-entrant and salient angles. Fig. 88 represents a twin grouping of rutile prisms which cross one another at angles of about 60° and 120°; and Fig. 89, a repeated twinning of rutile where eight individuals unite to form a rosette. Twinning often gives rise to very complex forms.

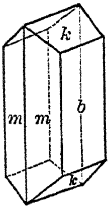

FIG. 84.

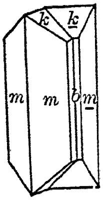

FIG. 85.

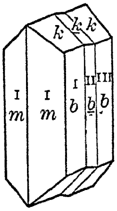

FIG. 86.

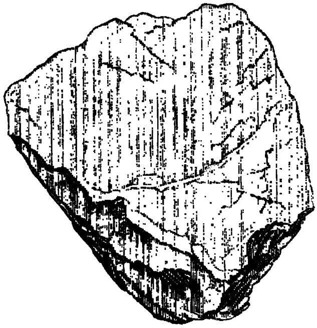

FIG. 87.

Although re-entrant angles are a prominent feature of twin crystals, they are not to be taken as a necessary indication of twinning. Crystals grow together in parallel and all possible accidental positions, giving rise occasionally to groupings with re-entrant angles which may closely resemble twin crystals, but are entirely distinct from them. Fig. 90 represents a parallel growth of octahedrons of magnetite.

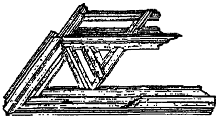

Fig. 88.

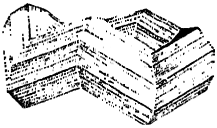

Fig.

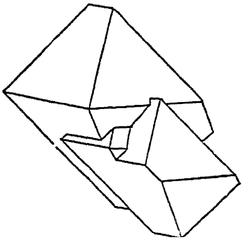

Fig. 90.

The Systems of Crystallization.—Although there is an almost unlimited variety in the forms of crystals, they can all be classified under the following six divisions, or *systems of crystallization:*

I. Isometric.
II. Tetragonal.
III. Hexagonal.
IV. Orthorhombic.
V. Monoclinic.
VI. Triclinic.

The character of the different systems, and the prominent forms which they present, will be described on subsequent pages.

Isometric System.

The forms in this system can be referred to three axes, which are at right angles to one another and of equal lengths (Fig. 91). Since the axes are alike, they are all designated by the symbol a, but in referring crystal faces to them a definite order is adopted, as a_1, a_2, and a_3.

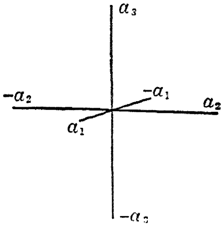

Fig. 91.

Forms of the Normal Group.—Galena Type.

All the forms and combinations of this group are characterized by having three axes of tetragonal, four of trigonal, and six of binary symmetry (Fig. 92); also by having three axial and six diagonal planes of symmetry (Figs. 93 and 94).

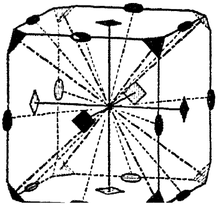

FIG. 92.

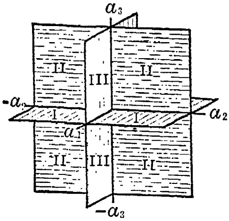

FIG. 93.

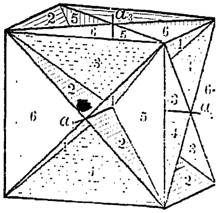

FIG. 94.

Cube.—The cube a (Fig. 95) has *six square faces*, each of which intersects one axis and is parallel to the other two. The symbol is (100). The interfacial angles are 90°. The faces are *all alike*. This is also true of the eight solid angles and twelve edges. (Compare distorted cubes, p. 166.) Galena, fluorite, and halite commonly crystallize in cubes.

Octahedron.—The octahedron o (Fig. 96) has *eight faces*, each of which intersects the three axes at equal distances from the center. The symbol is (111). The faces are *equilateral triangles* and the interfacial angles are 70° 32′. The faces are *alike*, as are also the six solid angles and the twelve edges. (Compare distorted octahedrons, p. 166.) Galena, magnetite, and fluorite often crystallize in octahedrons.

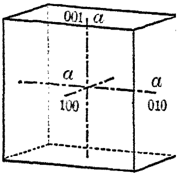

FIG. 95.

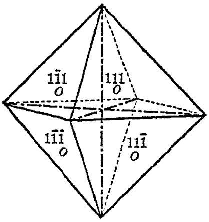

FIG. 96.

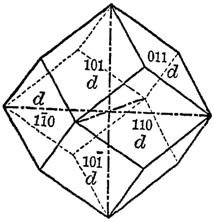

FIG. 97.

Dodecahedron.—The dodecahedron d (Fig. 97) called often the rhombic dodecahedron, has *twelve rhombic faces*, each of which intersects two of the axes at the same distance and is parallel to the third. The symbol is (110). The interfacial angles are 60°. The faces are *alike*, and so also are the twenty-four edges, but the solid angles are of two kinds, namely: those at the extremities of the axes, made by the meeting of four faces, and those at the centers of the octants, made by the meeting of three faces. Garnet and magnetite occur in dodecahedrons.

Crystals which show the combination of the cube *a*, the octahedron *o*, and the dodecahedron *d*, as illustrated by Figs. 98 to 104, will often be found. None of these combined forms receive a special name, but can be designated as follows: Fig. 98, a *combination* of cube and octahedron; Fig. 102, a *combination* of octahedron and dodecahedron; Fig. 104, a *combination* of cube, dodecahedron, and octahedron, etc. Galena, fluorite, and magnetite illustrate such combinations.

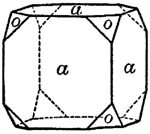

FIG. 98.

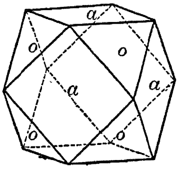

FIG. 99.

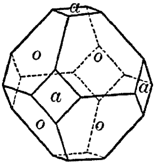

FIG. 100.

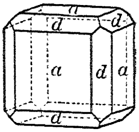

FIG. 101.

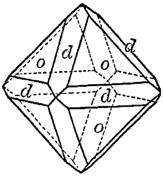

FIG. 102.

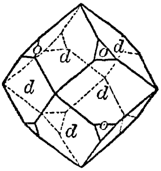

FIG. 103.

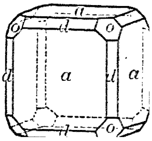

FIG. 104.

Trapezohedron.—The trapezohedron (Fig. 105) has *twenty-four similar faces*, each of which is a trapezium. Each face intersects one axis at a certain distance (unity) and the other two at equal multiples of unity. This form has two kinds of edges and three kinds of solid angles. A trapezohedron having the symbol (211) is the common form of garnet, analcite, and leucite. One with the symbol (311) would differ from the one figured in its interfacial angles, although the arrangement of the faces would be similar.

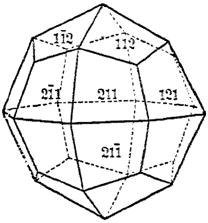

FIG. 105.

Fig. 106 (garnet) represents the trapezohedron *n* (211) in combination with the dodecahedron *d*; Fig. 107 (analcite), a combination of the same trapezohedron *n* with the cube *a*; and Fig. 108 (magnetite), the trapezohedron *m* (311) with the dodecahedron *d*.

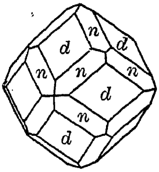

FIG. 106.

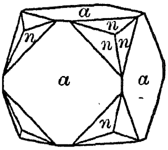

FIG. 107.

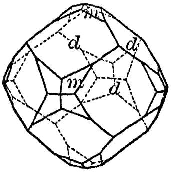

FIG. 108.

Trisoctahedron.—This form has *twenty-four triangular faces*, each cutting two of the axes at unity and the third at a multiple of unity. The one shown in Fig. 109 has the symbol (221). Fig. 110 represents a combination of this form *p* (221) with the octahedron *o*, which occurs in galena

Tetrahexahedron.—This form has *twenty-four triangular faces*, each cutting one axis at unity, a second at a multiple of unity, and a third at infinity. The one shown in Fig. 111 has the symbol (210). Fig. 112 is a combination of *f* (310) with the cube *a*, which occurs in fluorite.

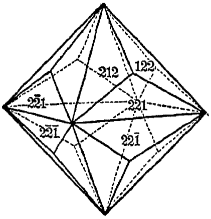

FIG. 109.

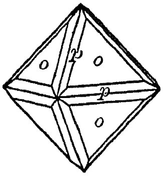

FIG. 110.

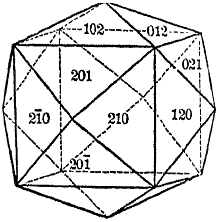

FIG. 111.

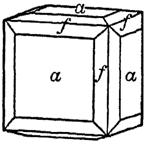

FIG. 112.

Hexoctahedron.—This form has *forty-eight triangular faces*,

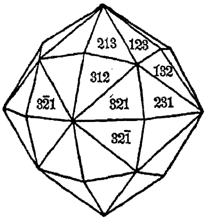

FIG. 113.

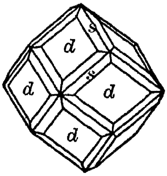

FIG. 114.

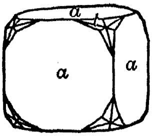

FIG. 115.

each cutting one axis at unity and the other two at different multiples of unity. The one shown in Fig. 113 has the symbol (321). Fig. 114 (garnet) represents a combination of this form *s* (321) with the dodecahedron *d*, and Fig. 115 (fluorite), the hexoctahedron *t* (421) with the cube *a*. Such combinations are only occasionally observed.

There are in all seven kinds of simple forms in the normal group: the cube, octahedron, dodecahedron, trapezohedron, trisoctahedron, tetrahexahedron, and hexoctahedron. It is possible that an isometric mineral may crystallize in any of these forms, although usually there are certain forms and combinations which are especially common in and characteristic of individual species. Thus galena and fluorite crystallize usually in cubes and octahedrons, or their combinations; magnetite, in octahedrons and dodecahedrons, or their combinations; garnet, in dodecahedrons and trapezohedrons (211), or their combinations; and leucite and analcite, in trapezohedrons (211). It is very seldom that galena is found in dodecahedrons, magnetite in cubes, or garnet in either cubes or octahedrons.

ISOMETRIC FORMS OF LOWER SYMMETRY THAN THAT PRESENTED BY THE NORMAL GROUP.

Pyritohedral Group.—Pyrite Type.

Crystals of this group are characterized by having three axes of binary and four of trigonal symmetry (Fig. 116); also three axial planes of symmetry (Fig. 93, p. 170).

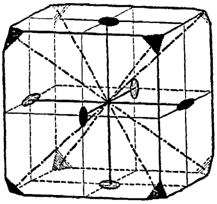

FIG. 116.

Pyritohedron.—This form (Fig. 117), sometimes called the pentagonal dodecahedron, has *twelve pentagonal faces*, corresponding in position to the alternating faces of the tetrahexahedron. The symbol of the pyritohedron figured is (210), the same as that of the tetrahexahedron (Fig. 111).

Diploid.—This form (Fig. 118) has *twenty-four faces* which correspond in position to half of the faces of the hexoctahedron. The symbol of the diploid figured is (321), the same as that of the hexoctahedron (Fig. 113).

The *cube*, *octahedron*, *dodecahedron*, *trisoctahedron*, and *trapezohedron* occur in this group, but they differ from the forms of the normal group in having a lower kind of symmetry. Thus it may generally be observed that the cubes of pyrite are *striated*, the striæ running in one direction on each cubic face, and at right angles to one another on adjacent faces (Fig. 119). The striations result from the tendency of the cube to crystallize in combination with the pyritohedron (Fig. 117). The crystallographic axes of such striated cubes are axes of *binary* symmetry, and *not* of tetragonal symmetry; therefore the cubes are not *normal* ones. Turn a cube of galena about its vertical axis and it will present the same appearance four times during a complete revolution, but a striated cube of pyrite similarly turned will present the same appearance only twice.

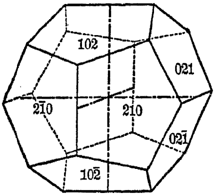

Fig. 117.

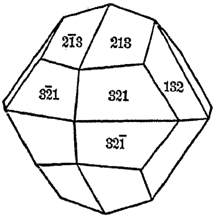

Fig. 118.

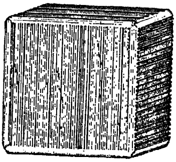

Fig. 119.

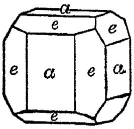

Fig. 120.

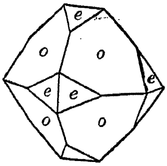

Fig. 121.

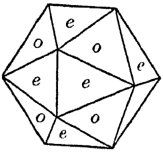

Fig. 122.

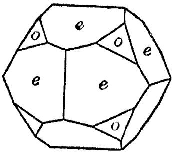

Fig. 123.

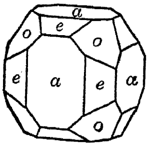

Fig. 124.

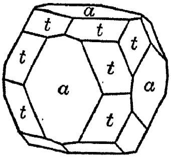

Fig. 125.

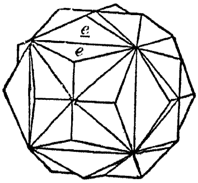

Fig. 126.

The combinations of the cube *a* (100) and the octahedron *o* (111) with the pyritohedron *e* (210) and the diploid *t* (421), represented by Figs. 120 to 125, illustrate forms which may be observed in pyrite and cobaltite, all of which serve to show the characteristic symmetry of this group. Fig. 126 represents a penetration twin of two pyritohedrons.

Tetrahedral Group.—Tetrahedrite Type.

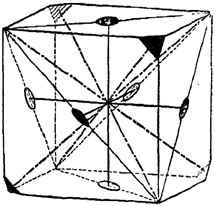
FIG. 127.

Crystals of this type are characterized by having three axes of binary and four of trigonal symmetry (Fig. 127), and also six diagonal planes of symmetry (Fig. 94, p. 170). The commonest form is the tetrahedron, from which the group derives its name.

Tetrahedron.—This form o (111) (Fig. 128) has *four faces*, corresponding in position to the alternating faces of the octahedron (Fig. 96). The faces are equilateral triangles, and the interfacial angles are alike, 109° 28′. Two tetrahedrons are possible which differ in position; o (111) (Fig. 128) being designated as the positive tetrahedron and o_1 $(1\bar{1}1)$ (Fig. 129), as the negative. The crystallographic axes join the centers of opposite edges. The positive and negative tetrahedrons may occur in combination, as represented by Fig. 133.

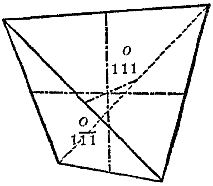

FIG. 128.

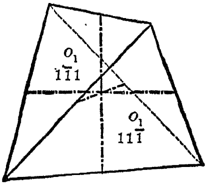

FIG. 129.

Tristetrahedron.—This form has *twelve triangular faces*, corresponding in position to half of the faces of the trapezohedron (Fig. 105). The form represented by Fig. 130 has the symbol (211).

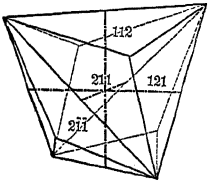

FIG. 130.

Possible forms in this group, which are occasionally seen in combination with other forms, are the *deltoid dodecahedron* (Fig. 131) and the *hexakistetrahedron* (Fig. 132), whose faces correspond to half of those of the trisoctahedron (Fig. 109) and the hexoctahedron (Fig. 113), respectively.

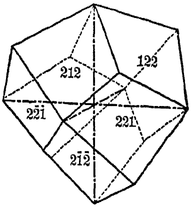

FIG. 131.

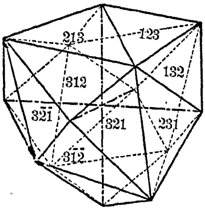

FIG. 132.

The cube *a* (100), the dodecahedron *d* (110), and the tetrahexahedron occur in combination with the foregoing tetrahedral forms. From Fig. 127 it may be seen that in the cube of this group the diagonally opposite solid angles are not alike. This is further shown by the combination of the cube and tetrahedron (Fig. 134). By comparing Figs. 134 and 137 with Figs. 98 and 103, respectively, it will be seen that both the cube and dodecahedron of this group differ from the *normal* cube and *normal* dodecahedron of the galena type.

Tetrahedrite, sphalerite, and boracite occur in tetrahedrons and tetrahedral combinations, and Figs. 133 to 138 represent some of the combinations which may be observed, where *o* is the positive

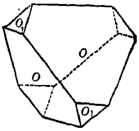

FIG. 133.

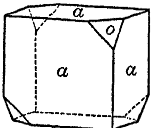

FIG. 134.

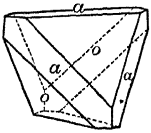

FIG. 135.

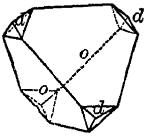

FIG. 136.

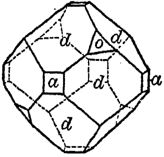

FIG. 137.

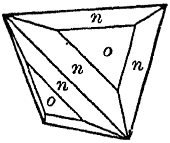

FIG. 138.

and o_1 the negative tetrahedron, *a* the cube, *d* the dodecahedron, and *n* the tristetrahedron (211).

TETRAGONAL SYSTEM.

The forms in this system are referred to three axes, all at right angles to one another. The two lateral axes a (Fig. 139) *are equal and interchange, while the vertical axis* c *differs from these in length and in character.* The length of the vertical axis has to be determined by the measurement of appropriate angles for each substance crystallizing in this system. In zircon, for example, $c = 0.640$, a being taken as unity.

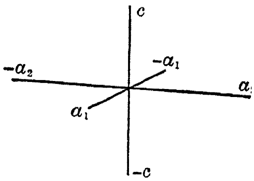

FIG. 139.

Forms of the Normal Group.—Zircon Type.

The crystals of this group are characterized by having a vertical axis of tetragonal symmetry and four axes of binary symmetry (Fig. 140); also one horizontal and four vertical planes of symmetry (Fig. 141).

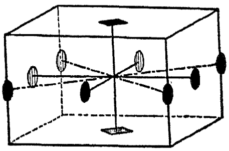

FIG. 140.

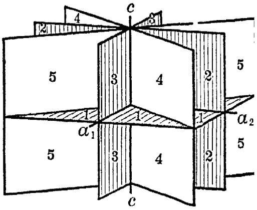

FIG. 141.

The forms are of three kinds: *pyramidal*, when the faces intercept the vertical and one or both of the horizontal axes; *prismatic*, when the faces are parallel to the vertical axis; and *pinacoidal*, when the faces are parallel to the horizontal axes.

Pyramids.—A form known as the *pyramid of the first order* (Fig. 142) has the symbol (111), where the third index refers to the *characteristic length of the vertical axis.* This form is characterized by having *eight similar faces* which are isosceles triangles, two kinds of edges, and two kinds of solid angles. (Compare the isometric octahedron (111), Fig. 96). Pyramids of this order are alike in the general arrangement of their faces, but those of different minerals will not have *the same interfacial angles,* since the lengths of their vertical axes are not alike. Fig. 142 represents the pyramid in zircon where $c = 0.640$; Fig. 143, one of braunite where $c = 0.985$ (the interfacial angles in this case are near those of the isometric octahedron, Fig. 96); and Fig. 144, one of octahedrite where $c = 1.777$.

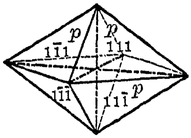

FIG. 142.

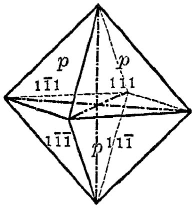

FIG. 143.

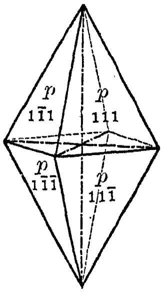

FIG. 144.

Another form, known as the *pyramid of the second order* (Fig. 145), has the symbol (101). This form, like that of the pyramid of the first order, has *eight similar faces* which are isosceles triangles, two kinds of edges, and two kinds of solid angles. Fig. 145 represents the pyramid of the second order of zircon where $c = 0.640$.

On any mineral there may be steeper or flatter pyramids than the unit-forms (111) and (101), according as the faces intercept the vertical axis at a multiple or fraction of its characteristic length.

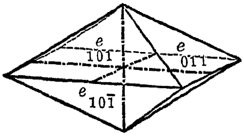

FIG. 145.

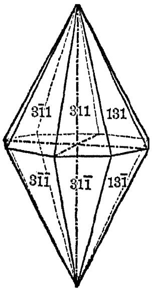

FIG. 146.

Fig. 146 represents a form known as the *ditetragonal pyramid*, having eight similar faces above and eight below. Its symbol is (311), and the vertical axis corresponds to that of zircon, $c = 0.640$.

Prisms.—Square prisms are very common and characteristic forms in this group. The form *m* (110) (Fig. 147) is called a *prism of the first order* and the form *a* (100) (Fig. 148) a *prism of the second order.* Each consists of *four similar faces* with interfacial angles of exactly 90°.

Fig. 149 represents a form (210) which has eight similar faces and is known as a *ditetragonal prism.*

Fig. 150 is a plan, or horizontal projection of the lateral axes, together with the trace of the prism of the first order *m* and the second order *a*. The necessity for having prisms and pyramids of two orders will become evident when the tetragonal combinations are considered.

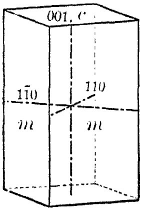

FIG. 147.

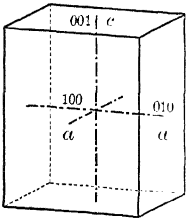

FIG. 148.

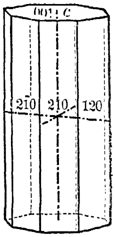

FIG. 149.

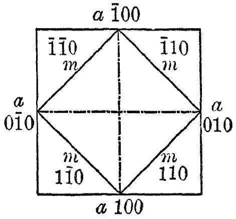

FIG. 150.

There is nothing in the molecular character of a substance to determine the length of its prismatic forms, as the prisms which occur on a mineral may be either long or short, wholly independent of the characteristic length of the vertical axis *c*. The pyramidal faces which terminate the prisms have, however, *definite inclinations*, and from the angles of these the length of the vertical axis *c* is calculated.

Base or Pinacoid.—The form *c* (001) is a very common one, and consists of *two similar parallel faces*, the top and bottom ones in Figs. 147 to 149.

Combinations.—The following examples will serve to show the variations in habit resulting from the combinations of tetragonal forms in different minerals. The frequent occurrence of the forms with simple indices is noticeable: *a* (100), *c* (001), *m* (110), *p* (111), and *e* (101).

The interfacial angles $a \wedge a$, $m \wedge m$, $a \wedge c$, and $m \wedge c = 90°$ and $a \wedge m = 45°$.

Zircon (Figs. 142 and 151 to 155).—Axis $c = 0.640$. Angles $p \wedge p = 56° \; 40'$ and $c \wedge p = 42° \; 10'$. These crystals commonly present the combination of the prism of the first order m (110) with the pyramid of the first order p (111). The steep pyramid of the first order u (331) and the ditetragonal pyramid x (311) are occasionally observed. The base c (001) is exceeding rare on zircon crystals.

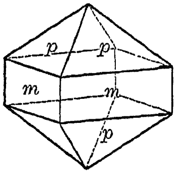

Fig. 151.

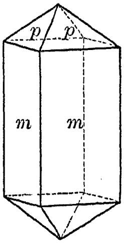

Fig. 152.

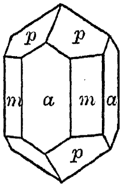

Fig. 153.

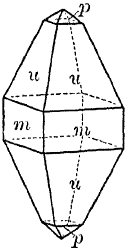

Fig. 154.

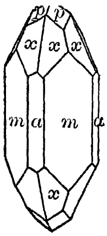

Fig. 155.

Vesuvianite (Figs. 156 to 159).—Axis $c = 0.537$. Angles $p \wedge p = 50° \; 39'$ and $c \wedge p = 37° \; 13'$. These crystals usually show the prism of the first order m (110) and of the second order a (100), terminated either by the basal plane c (001), the pyramid of the first order p (111), or by a combination of both c and p.

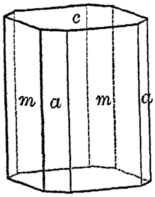

Fig. 156.

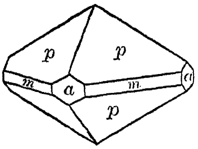

Fig. 157.

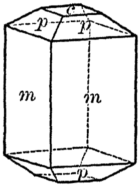

Fig. 158.

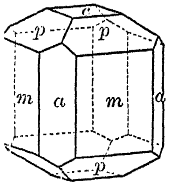

Fig. 159.

Cassiterite (Figs. 160 to 162).—Axis $c = 0.672$. Angles $p \wedge p = 58° \; 19'$ and $c \wedge p = 43° \; 33'$. On crystals of this mineral the pyramid and prism of the first order, p (111) and m (110), and the prism of the second order a (100) are the prominent forms. The pyramid of the second order e (101) and the base c (001) occur in combination with these. Twin crystals are common with the pyramid of the second order e $(0\bar{1}1)$ as twinning-plane.

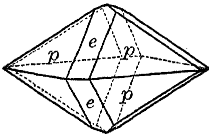

FIG. 160.

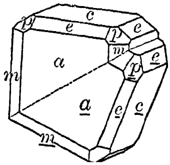

FIG. 161.

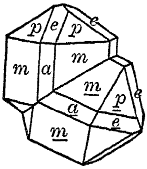

FIG. 162.

Rutile (Figs. 163 to 166).—Axis $c = 0.644$. Angles $p \wedge p =$ 56° 52′ and $c \wedge p = 42° 20'$. The crystals are usually prismatic and often capillary. Prisms of the first and second orders, m (110) and a (100), occur and are terminated by the pyramids of the first and second orders, p (111) and e (101). Fig. 164 is a basal projection of Fig. 163, and shows the symmetrical development of the faces of a tetragonal crystal about the vertical axis. Twin crystals of rutile are very common, a pyramid of the second order (101) being the twinning-plane. Often a network of prisms, crossing at angles of nearly 60° and 120° (Fig. 165), and zigzag groups (Fig. 166) result.

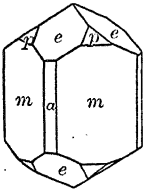

FIG. 163.

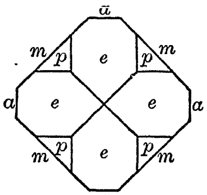

FIG. 164.

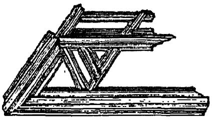

FIG. 165.

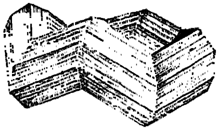

FIG. 166.

Octahedrite (Figs. 167 and 168).—Axis $c = 1.777$. Angles $p \wedge p =$ 82° 9′ and $c \wedge p = 68° 18'$. The common form is the pyramid of the first order p (111) (Fig. 144). The forms shown in Figs. 167 and 168 are the flat pyramids of the first and second orders, z (113) and x (103), the prism of the first order a (100), and the base c (001).

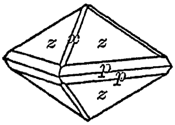

FIG. 167.

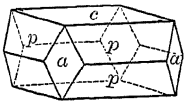

FIG. 168.

Apophyllite (Figs. 169 to 172).—Axis $c = 1.251$. Angles $p \wedge p =$ 76° 0′ and $c \wedge p = 60° 32'$. This mineral is characterized by the almost constant occurrence of the pyramid of the first order *p* (111) in combination with the prism of the second order *a* (100). The basal plane *c* (001) is usually present, and is often prominent (Fig. 172). The ditetragonal prism *y* (310) may also occasionally be observed.

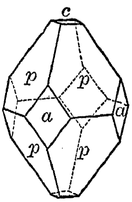

FIG. 169.

FIG. 170.

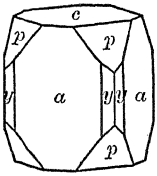

FIG. 171.

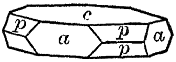

FIG. 172.

TETRAGONAL FORMS OF LOWER SYMMETRY THAN THAT PRESENTED BY THE NORMAL GROUP.

Tri-Pyramidal Group.—Scheelite Type.

This group is characterized by having a vertical axis of tetragonal symmetry and one horizontal plane of symmetry. (Compare Figs. 140 and 141, p. 177).

The characteristics of the group may be illustrated by scheelite and scapolite.

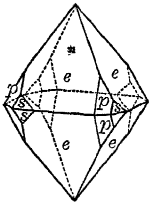

FIG. 173.

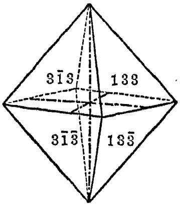

FIG. 174.

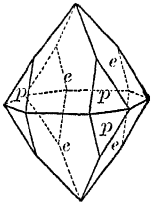

FIG. 175.

Scheelite (Figs. 173 and 175).—Axis $c = 1.536$. Angles $p \wedge p = 79^\circ 55'$ and $c \wedge p = 65^\circ 16'$. Fig. 173 represents a combination of the pyramid of the first order *p* (111), of the second order *e* (101), and a form *s* having the symbol (131) and known as a *pyramid of the third order.* If the form *s* occurred alone it would be a tetragonal pyramid, with its horizontal edges having the directions $3a : a$ on the lateral axes. A pyramid of the third order (133), not so acute as the form s, is represented by Fig. 174. A common habit with scheelite is a combination of the pyramids of the first and second orders, p and e (Fig. 175).

Scapolite (Figs. 176 to 178).—Axis $c = 0.438$. Angles $p \wedge p = 43° 45'$ and $c \wedge p = 31° 48'$. The figures illustrate combinations of the prisms of the first and second orders, m (110) and a (100), with the pyramid of the first order p (111); while Fig. 178 shows the additional pyramid z (311) of the third order.

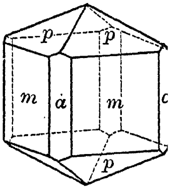

Fig. 176.

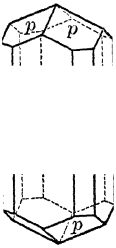

Fig. 177.

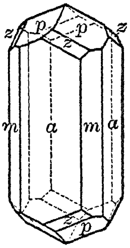

Fig. 178.

It should be observed that the forms s (131) of scheelite and z (311) of scapolite are *tetragonal pyramids*, while the form with corresponding indices in the normal group is a ditetragonal pyramid (Fig. 146).

Sphenoidal Group.—Chalcopyrite Type.

This group is characterized by having a vertical axis of binary symmetry and two horizontal axes of binary symmetry; also two vertical planes of symmetry (numbers 4 and 5) (Fig. 141, p. 177). The forms are illustrated by chalcopyrite.

Chalcopyrite (Figs. 179 to 185).—Axis $c = 0.985$. Angles $p \wedge p_1 = 70° 7\frac{1}{2}'$ and $c \wedge p = 54° 20'$. The form p (111) (Fig. 179) is called a *sphenoid*. It has four similar faces, which correspond in their relation to the axes to the alternating faces of the tetragonal pyra-

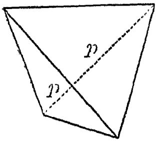

Fig. 179.

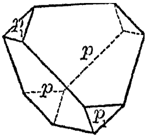

Fig. 180.

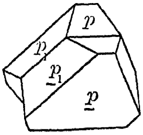

Fig. 181.

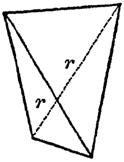

Fig. 182.

mid of the first order (Fig. 143). The form is analogous to the isometric tetrahedron (Fig. 128), being almost identical with it in its interfacial angles, since the length of the vertical axis of chalcopyrite is so nearly equal to that of the lateral axes. The positive sphenoid *p* (111) and the negative sphenoid *p* $(1\bar{1}1)$ occur in combination (Fig. 180), also twinned (Fig. 181). The acute sphenoid *r* (Fig. 182) having the symbol (332) and the pyramid of the second order *z* (Figs. 183 and 184) having the symbol (201) are occasionally observed. The twinning-plane of Figs. 181 and 184 is $(\bar{1}\bar{1}1)$. Fig. 185 represents a combination of an acute sphenoid Φ (772) with a form χ (122), known as a scalenohedron, but the symbols of these two forms are questionable, because the faces are striated and the inclinations therefore not accurately determined.

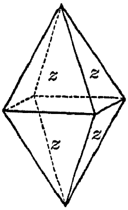

FIG. 183.

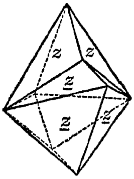

FIG. 184.

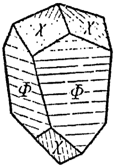

FIG. 185.

Hexagonal System.

The forms in this system are referred to four axes. The three lateral axes a_1, a_2, *and* a_3 (Fig. 186) *are equal and interchangeable, and cross at angles of* 60° *and* 120°, *while the vertical axis c is of different length and at right angles to them.* The length of the vertical axis must be determined by the measurement of appropriate angles for each substance crystallizing in this system. In beryl, for example, $c = 0.499$, the lateral axes being taken as unity.

Fig. 187 represents a plan of the lateral axes. In giving the parameters and indices of the forms, the *order* in which the axes are taken, a_1, a_2, and a_3, and also the positive and negative directions, as indicated in the figure, *should be carefully observed.*

On account of the axial angles of 60° and 120° there are certain relations of the crystal faces to the horizontal axes, represented by Fig. 188, which should be carefully considered. A face intersecting the unit lengths of adjacent axes will be parallel to the third axis; hence the parameter relation $a_1 : \infty a_2 : -a_3$ and indices $(10\bar{1})$. A face going from unity (a) on one axis to a multiple of unity (na) on an adjacent axis will intersect the third axis at $\frac{n}{n-1}a$. Thus when $n = 2$, the face may have the parameter relation $2a_1 : 2a_2 : -a_3$ and indices $(11\bar{2})$. When n is a quantity greater than 1 and less than 2, for example $\frac{3}{2}$, the parameter relation may be $\frac{3}{2}a_1 : 3a_2 : -a_3$, indices $(21\bar{3})$. In every case the third index will be equal to the sum of the first and second indices, with the opposite sign. In the complete symbols of hexagonal forms there will be a fourth index, expressing the relation on the vertical axis.

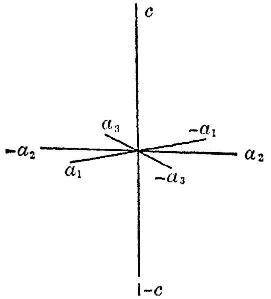

FIG. 186.

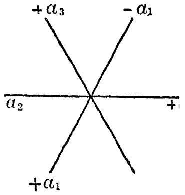

FIG. 187.

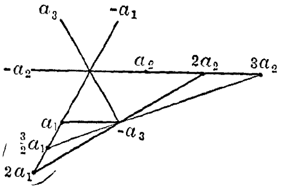

FIG. 188.

Forms of the Normal Group.—Beryl Type.

The crystals of this group are characterized by having a vertical axis of hexagonal symmetry and six horizontal axes of binary symmetry (Fig. 189); also one horizontal and six vertical planes of symmetry (Fig. 190).

The forms are of three kinds: *pyramidal*, when the faces intersect the vertical and the horizontal axes; *prismatic*, when the faces are parallel to the vertical axis; and *pinacoidal*, when the faces are parallel to the three horizontal axes.

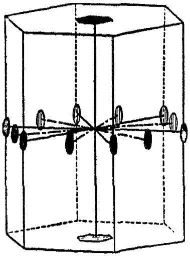

FIG. 189.

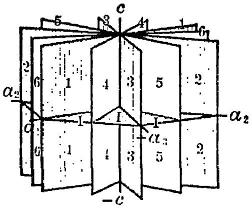

FIG. 190.

Pyramids.—A form known as the *pyramid of the first order* (Fig. 191) has the symbol $(10\bar{1}1)$. The twelve faces, six above and six below, are *alike*, and are isosceles triangles. The six upper ones have, respectively, the following indices: $(10\bar{1}1)$, $(01\bar{1}1)$, $(\bar{1}101)$, $(\bar{1}011)$, $(0\bar{1}11)$, $(1\bar{1}01)$. A form known as the pyramid of the second order (Fig. 192) has the symbol $(11\bar{2}2)$; in this the twelve faces are isosceles triangles, the six upper ones having the following indices: $(11\bar{2}2)$, $(\bar{1}2\bar{1}2)$, $(\bar{2}112)$, $(\bar{1}\bar{1}22)$, $(1\bar{2}12)$, $(2\bar{1}\bar{1}2)$. There may be steeper or flatter pyramids of either order, according as the vertical axes are cut at a multiple or a fraction of the unit length.

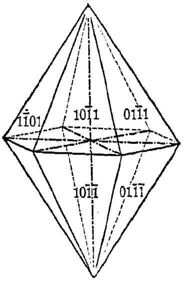

FIG. 191.

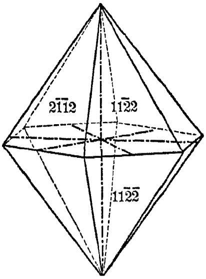

FIG. 192.

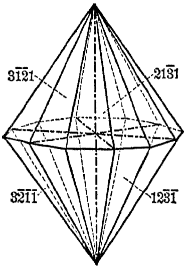

FIG. 193.

Fig. 193 represents a form with twelve similar faces above and twelve below, known as the *dihexagonal pyramid.* It is only occasionally that a complicated form of this kind is observed in combinations. One is shown in Fig. 203 (beryl) lettered *n*. The form represented by Fig. 193 has the symbol $(21\bar{3}1)$, where $c = 0.499$, the length of the vertical axis of beryl.

Prisms.—Corresponding to the pyramids are two *hexagonal prisms: the prism of the first order*, *m* (Fig. 194), with the symbol $(10\bar{1}0)$, and *the prism of the second order*, *a* (Fig. 195), with the symbol $(11\bar{2}0)$. Each kind of prism has *six similar faces*, with interfacial angles of 60°.

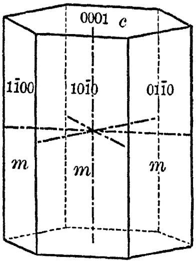

FIG. 194.

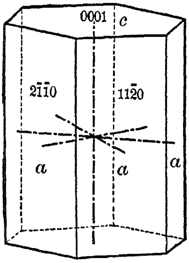

FIG. 195.

Fig. 196 gives a plan of the horizontal axes, together with the trace of the prism of the first order *m* and of the second order *a*. The necessity of having pyramids and prisms of the two orders will become evident when some of the crystal combinations are considered.

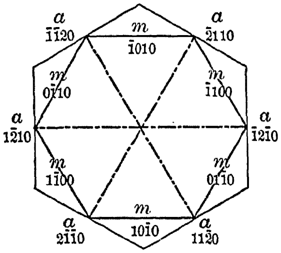

FIG. 196.

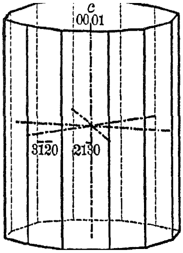

FIG. 197.

The rare *dihexagonal prism* having twelve similar faces is shown by Fig. 197, which represents the form $(21\bar{3}0)$.

The prisms of a hexagonal mineral may be either long or short, wholly independent of the characteristic length of the vertical axis.

Base or Pinacoid.—The form *c*, having the symbol (0001), consists of two similar faces, the top and bottom ones of Figs. 194, 195, and 197. The basal plane is exactly at right angles to the prismatic faces.

Combinations.—The following representations of crystals of different minerals illustrate some combinations of hexagonal forms. In these the prevalence of the forms with simple indices, c (0001), m $(10\bar{1}0)$, and p $(10\bar{1}1)$ is noticeable. The interfacial angles $m \wedge c$ and $a \wedge c = 90°$, $m \wedge m$ and $a \wedge a = 60°$, and $m \wedge a = 30°$.

Beryl (Figs. 198–203).—Axis $c = 0.499$. Angles $p \wedge p = 28° 54'$ and $c \wedge p = 29° 56'$. The common habit of beryl is a combination of the prism of the first order, m $(10\bar{1}0)$, with the base c (0001). Crystals showing pyramidal forms of the first order, p $(10\bar{1}1)$, and of the second order, s $(11\bar{2}1)$, and the prism of the second order, a $(11\bar{2}0)$, are rather exceptional. Fig. 202 is a basal projection of Fig. 201, illustrating the development of similar faces in sets of six about the vertical axis. Fig. 203 represents a highly modified crystal, with the prism m, terminated by a dihexagonal pyramid n $(31\bar{4}1)$, two pyramids of the second order, s and d $(33\bar{6}4)$, the pyramid of the first order p, and the base c.

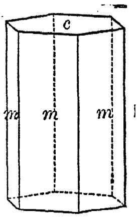

FIG. 198.

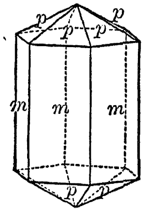

FIG. 199.

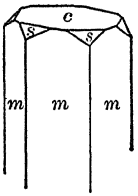

FIG. 200.

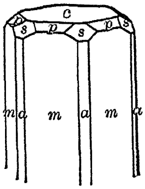

FIG. 201.

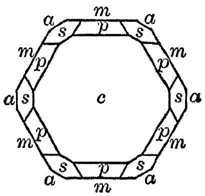

FIG. 202.

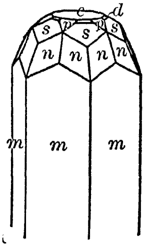

FIG. 203.

Pyrrhotite (Figs. 204 and 205).—Axis $c = 0.870$. Angles $p \wedge p = 41° 30'$ and $c \wedge p = 45° 8'$. The crystals of this mineral are usually tabular, owing to the prominence of the base c (0001), and show the forms of the prism of the first order *m* $(10\bar{1}0)$, and two pyramids of the first order, *p* $(10\bar{1}1)$ and *u* $(40\bar{4}1)$.

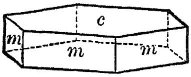

FIG. 204.

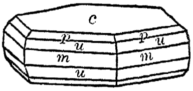

FIG. 205.

Hanksite (Fig. 206).—Axis $c = 1.014$. Angles $p \wedge p = 44° 41'$ and $c \wedge p = 49° 30'$. The common combination is that of the prism and pyramid of the first order, *m* $(10\bar{1}0)$ and *p* $(10\bar{1}1)$, with the basal plane *c* (0001).

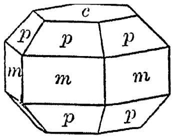

FIG. 206.

HEXAGONAL FORMS OF LOWER SYMMETRY THAN THAT PRESENTED BY THE NORMAL TYPE.

Tri-Pyramidal Group.—Apatite Type.

This group is characterized by having a vertical axis of hexagonal symmetry and one horizontal plane of symmetry. (Compare Figs. 189 and 190.)

The characteristics of the group may be illustrated by apatite and vanadinite.

Apatite (Figs. 207, 209 and 210).—Axis $c = 0.735$. Angles $p \wedge p = 37° 44'$ and $c \wedge p = 40° 18'$. Fig. 207 represents a somewhat complex crystal, with the prisms of the first and second orders, *m* $(10\bar{1}0)$ and *a* $(11\bar{2}0)$, terminated by the base *c* (0001), three pyramids of the first order, *y* $(20\bar{2}1)$, *p* $(10\bar{1}1)$, and *r* $(10\bar{1}2)$, a pyramid of the second order *s* $(11\bar{2}1)$, and a hexagonal pyramid μ $(21\bar{3}1)$, known as a *pyramid of the third order*.

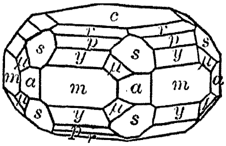

FIG. 207.

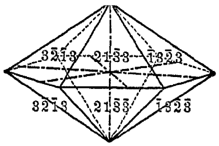

FIG. 208.

A pyramid of the third order having the symbol $(12\bar{3}3)$, but not so acute as the form μ, is represented by Fig. 208. It will be observed that the horizontal axes do not join the opposite solid angles, as in the pyramid of the first order (Fig. 191), nor the centers of opposite edges, as in the pyramid of the second order (Fig. 192). The simple crystals of apatite which are ordinarily observed (Figs. 209 and 210) do not appear to differ from forms of the normal group, but their peculiar symmetry can be revealed by etching with acid, as explained beyond under quartz (page 198).

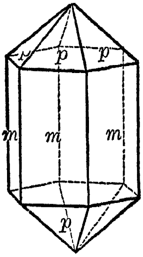

FIG. 209.

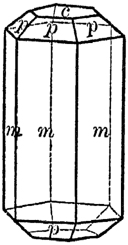

FIG. 210.

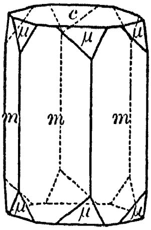

FIG. 211.

Vanadinite (Fig. 211).—Axis $c = 0.712$. The figure illustrates a rather simple combination of a prism of the first order m $(10\bar{1}0)$ and base c (0001), with a pyramid of the third order μ $(21\bar{3}1)$.

It should be observed that the form μ $(21\bar{3}1)$ in this group is a *hexagonal pyramid*, while in the normal group a form with corresponding indices is a dihexagonal pyramid (Fig. 193).

Hemimorphic Group.—Iodyrite Type.

This group is characterized by having a vertical axis of hexagonal symmetry and six vertical planes of symmetry. The peculiarity of the crystals is the development of different forms at opposite extremities of the vertical axis, as illustrated by Fig. 212 of the rare mineral iodyrite, and Fig. 213 of zincite. The pyramids of iodyrite are u $(40\bar{4}1)$ and π $(40\bar{4}5)$.

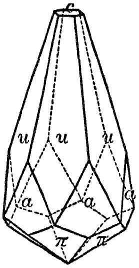

FIG. 212.

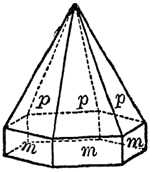

FIG. 213.

RHOMBOHEDRAL FORMS OF THE HEXAGONAL SYSTEM.

In crystals of this class the forms are referred to the hexagonal system of axes (Fig. 186), but the vertical axis *c* is one of *trigonal* and not of hexagonal symmetry. Many common minerals crystallize in this class, which is often designated as the *rhombohedral system.*

Forms of the Normal Rhombohedral Group.—Calcite Type.

The forms of this group are characterized by having a vertical axis of trigonal symmetry and three horizontal axes of binary symmetry (Fig. 214); also by having three vertical planes of symmetry, 4, 5, and 6 (Fig. 190, p. 186).

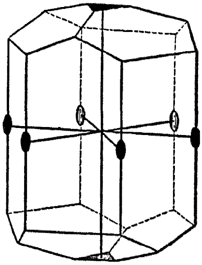

FIG. 214.

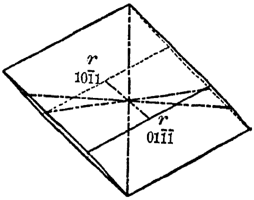

FIG. 215.

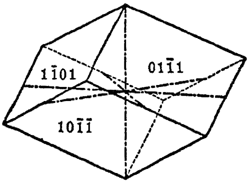

FIG. 216.

Rhombohedrons.—A rhombohedron (Fig. 215) is characterized by having *six similar faces* which are rhombs and correspond in their axial relations to the alternating faces of the hexagonal pyramid of the first order (Fig. 191). Rhombohedrons are designated as *positive* (Fig. 215) when a face above is toward the observer, and *negative* (Fig. 216) when an edge above is toward the observer.

When the faces intercept the vertical axis at unity, the symbols of these forms are, respectively, $(10\bar{1}1)$ and $(01\bar{1}1)$. Furthermore, rhombohedrons are called *obtuse* or *flat* when the solid angles at the extremities of the vertical axis are obtuse, and *acute* or *steep* when these solid angles are acute. Fig. 218 represents an obtuse, and Fig. 221, an acute rhombohedron of calcite. They also have two kinds of solid angles; those at the extremities of the vertical axis, where the plane angles of the faces are alike, and six others in which the plane angles of the faces are of two kinds, either two acute and one obtuse (Fig. 218), or two obtuse and one acute (Fig. 221). The edges are of two kinds, six (three above and three below) running to the extremities of the vertical axis, and six going zigzag around the crystal.

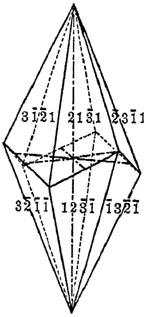

FIG. 217.

Scalenohedron.—This is a form (Fig. 217) having *twelve similar faces*, six above and six below, corresponding in position to the alternating pairs of faces of the dihexagonal pyramid (Fig. 193). The faces are scalene triangles, hence the name *scalenohedron*. The edges which meet at the extremities of the vertical axis are of two kinds, long and short, alternately disposed; while the six middle edges are alike, and run zigzag around the crystal, as in the rhombohedron (Fig. 215). Fig. 217 represents the scalenohedron $(21\bar{3}1)$ which commonly occurs on calcite.

Combinations.—Pyramids of the second orders (Fig. 192), prisms *m* and *a* of the first and second orders (Figs. 194 and 195), the dihexagonal prism (Fig. 197), and the basal plane *c* (0001) occur in combination with rhombohedrons and scalenohedrons. The basal plane *c* when it truncates the top of a rhombohedron is an equilateral triangle (Fig. 223).

Calcite (Figs. 218 to 233).—Axis $c = 0.854$. Angles $r \wedge r = 74°$ 55′ and $c \wedge r = 44° 36\frac{1}{2}'$. This mineral presents a greater variety of habits than almost any other. Of the rhombohedral type the negative rhombohedrons *e* $(01\bar{1}2)$ and *f* $(02\bar{2}1)$ and the positive rhombohedron *r* $(10\bar{1}1)$ are the commonest. The angles of the negative rhombohedron h $(03\bar{3}2)$ are 91° 42′; hence this form, when it occurs without modifications, closely resembles a cube.

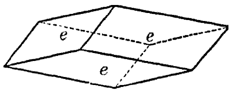

FIG. 218.

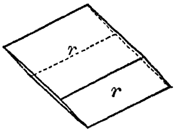

FIG. 219.

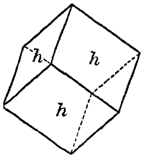

FIG. 220.

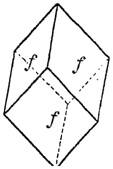

FIG. 221.

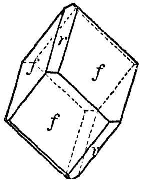

FIG. 222.

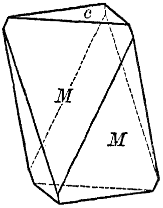

FIG. 223.

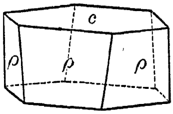

FIG. 224.

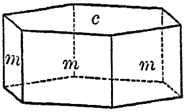

FIG. 225.

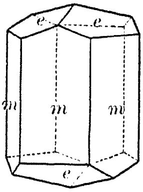

FIG. 226.

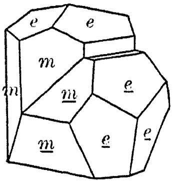

FIG. 227.

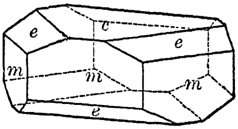

FIG. 228.

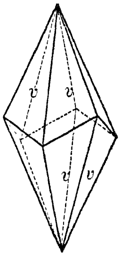

FIG. 229.

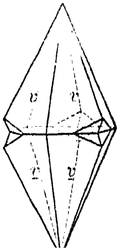

FIG. 230.

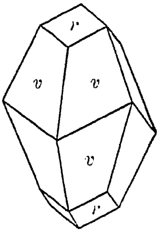

FIG. 231.

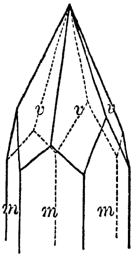

FIG. 232.

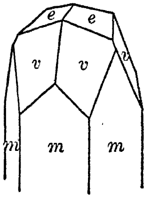

FIG. 233.

Fig. 222 is a combination of the two rhombohedrons r and f. Figs. 223 and 224 are combinations of the acute rhombohedrons M $(40\bar{4}1)$ and ρ $(16.0.\overline{16}.1)$ with the base c. The last figure bears a close resemblance to the combination of the prism m of the first order and base c (Fig 225). A prismatic type is common, the prism being either long or short and usually of the first order, m $(10\bar{1}0)$. The prisms are terminated by the base c, by rhombohedrons, most often e (Fig. 226), and by scalenohedrons (Figs. 232 and 233). The scalenohedron most often observed is v $(21\bar{3}1)$ (Figs. 229 to 233). The twinning-plane of Fig. 227 is r $(0\bar{1}11)$, and the vertical axes are inclined nearly 90° to one another. Fig. 230 is a twinned scalenohedron with the base as the twinning-plane.

Corundum (Figs. 234 to 236).—Axis $c = 1.363$. Angles $r \wedge r = 93° 56'$ and $c \wedge r = 57° 34'$. Crystals of this mineral usually show the prism and pyramid of the second order, a $(11\bar{2}0)$ and n $(22\bar{4}3)$, in combination with the base c (0001) and rhombohedron r $(10\bar{1}1)$.

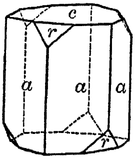

Fig. 234.

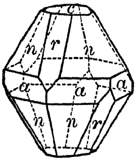

Fig. 235.

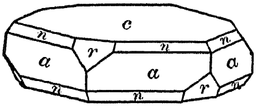

Fig. 236.

Hematite (Figs. 237 to 241).—Axis $c = 1.366$. Angles $r \wedge r = 94° 0'$ and $c \wedge r = 57° 37'$. The rhombohedron r $(10\bar{1}1)$ (Fig. 237) occasionally occurs without modification and resembles a cube, since its angles are near 90°. Crystals usually show combinations of the rhombohedron r with the base c and a pyramid of the second order, n $(22\bar{4}3)$. Very flat crystals (scales) are common with the basal plane c or flat rhombohedrons u $(10\bar{1}4)$ or x $(0.1.\bar{1}.12)$ prominent.

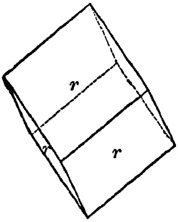

Fig. 237.

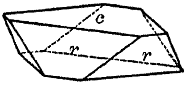

Fig. 238.

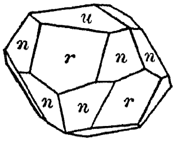

Fig. 239.

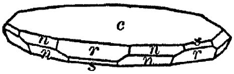

Fig. 240.

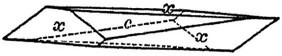

Fig. 241.

Chabazite (Figs. 242 and 243).—Axis $c = 1.086$. Angles $r \wedge r = 85° 14'$. The common form is the rhombohedron r $(10\bar{1}1)$, which closely resembles a cube. Fig. 242 represents this form in combination with the negative rhombohedrons e $(01\bar{1}2)$ and f $(02\bar{2}1)$.

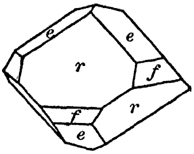

FIG. 242.

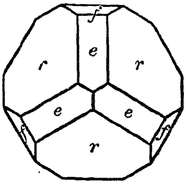

FIG. 243.

Fig. 243 is a basal projection of Fig. 242 and shows the symmetrical development of the rhombohedral faces r, e, and f about the vertical axis.

RHOMBOHEDRAL FORMS OF LOWER SYMMETRY THAN THAT PRESENTED BY THE NORMAL TYPE.

Hemimorphic Group.—Tourmaline Type.

The crystals of this group are characterized by having a vertical axis of trigonal symmetry and three vertical planes of symmetry.

It is characteristic of crystals of this group that the faces at opposite extremities of the vertical axis are not alike. The forms occur on *tourmaline* (Figs. 244 to 247).—Axis $c = 0.448$. Angles $r \wedge r = 46° 52'$ and $c \wedge r = 27° 20'$. The crystals of this mineral usually present the combination of the triangular prism m $(10\bar{1}0)$ and the hexagonal prism of the second order a $(11\bar{2}0)$, which are terminated above by the forms r $(10\bar{1}1)$, o $(02\bar{2}1)$, and occasionally u $(32\bar{5}1)$, and below by r $(01\bar{1}\bar{1})$, o $(20\bar{2}\bar{1})$, and c $(000\bar{1})$.

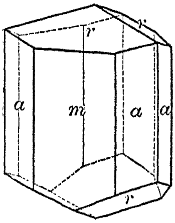

FIG. 244.

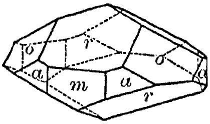

FIG. 245.

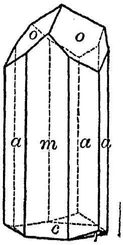

FIG. 246.

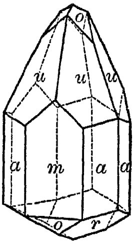

FIG. 247.

Trirhombohedral Group.—Phenacite Type.

The crystals of this group are characterized by having a vertical axis of trigonal symmetry and a center of symmetry, but no planes of symmetry.

The forms which are especially characteristic are hexagonal prisms, usually *a* $(11\bar{2}0)$, and rhombohedrons of the first, second, and third orders. The three kinds of rhombohedrons correspond in their axial relations to one half of the faces of the hexagonal pyramids of the first and second orders (Figs. 191 and 192), and to one quarter of the faces of the dihexagonal pyramid (Fig. 193).

Phenacite (Fig. 248).—Axis $c = 0.661$. The figure represents a prism of the second order *a* $(11\bar{2}0)$, in combination with a rhombohedron of the third order *x* $(21\bar{3}2)$.

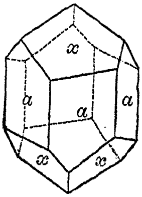

FIG. 248.

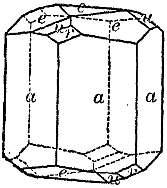

FIG. 249.

Willemite (Fig. 249).—Axis $c = 0.677$. Here the prism of the second order *a* is in combination with two rhombohedrons of the first order, *r* $(10\bar{1}1)$ and *e* $(01\bar{1}2)$, and a rhombohedron of the second order *u* $(2\bar{1}\bar{1}3)$.

Dioptase (Figs. 250 and 251).—Axis $c = 0.534$. The figures represent combinations of the prism of the second order *a*, with a rhombohedron of the first order *s* $(02\bar{2}1)$, and of the third order *x* $(13\bar{4}1)$.

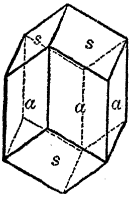

FIG. 250.

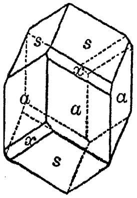

FIG. 251.

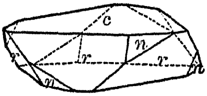

FIG. 252.

Ilmenite (Fig. 252).—Axis $c = 1.385$. The figure presents a combination of a rhombohedron of the first order r $(10\bar{1}1)$, and one of the second order n $(22\bar{4}3)$, with the base c (0001).

Trapezohedral Group.—Quartz Type.

The crystals of this group are characterized by having a vertical axis of trigonal symmetry and three horizontal axes of binary symmetry (Fig. 214), but no planes of symmetry.

Quartz (Figs. 253 to 264).—Axis $c = 1.100$. Angles $r \wedge r = 85° 46'$, $r \wedge z = 46° 16'$ and $r \wedge m = 38° 13'$. The forms which generally occur are the prism of the first order m $(10\bar{1}0)$, and the positive and negative rhombohedrons, r $(10\bar{1}1)$ and z $(01\bar{1}1)$, often with the two last forms about equally developed (Figs. 253 and 254). An unequal development of these rhombohedrons (Fig. 255) is also common. Although not indicated by their simple combinations, quartz crystals have a peculiar *right* or *left* symmetry. This is shown by the development of the form x $(51\bar{6}1)$, on the right-handed crystal (Fig. 256), and x $(6\bar{1}\bar{5}1)$ on the left-handed crystal (Fig. 257). The form which the six x faces of one of these crystals would produce is known as a *trapezohedron.* Its faces correspond in their axial relation to one quarter of the faces of the dihexagonal pyramid (Fig. 193). The right- and left-handed trapezohedrons having the symbols $(21\bar{3}1)$ and $(3\bar{1}\bar{2}1)$ are shown by Figs. 258 and 259. These forms, like the right and left hand, are symmetrical with reference to a plane passed between them, but cannot by any turning be made to occupy the same position. In this group the form s $(11\bar{2}1)$ (Fig. 256) develops as a triangular pyramid (Fig. 260), and has the same symbol as a

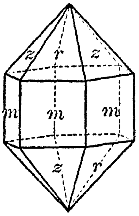

FIG. 253.

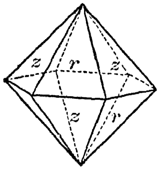

FIG. 254.

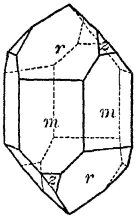

FIG. 255.

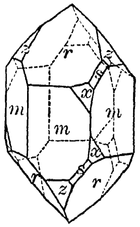

FIG. 256.

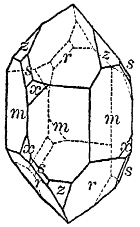

FIG. 257.

pyramid of the second order of the normal group (Fig. 192). Positive and negative acute rhombohedrons, *M* ($30\bar{3}1$) and M_1 ($03\bar{3}1$) (Figs. 261 and 262), often occur.

Twin crystals are very common, and are of a peculiar character.

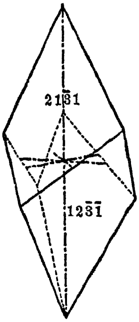

FIG. 258.

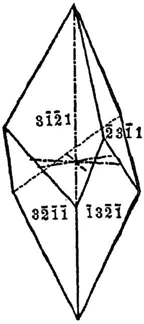

FIG. 259.

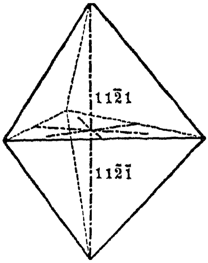

FIG. 260.

The twinning-plane is usually the prism of the first order *m*, so that the positive rhombohedron *r* of the crystal in the normal position coincides with the negative rhombohedron *z* of the crystal in the twinned position. The parts of the individual in the normal and twin position interpenetrate in a very irregular manner (Fig. 262), and the twin character of the crystal is not usually revealed by its external form. Often, however, the faces of either the positive or negative rhombohedrons are somewhat corroded (etched) (Fig. 262), and then the irregular lines of penetration between the *r* and *z* and the *M* and M_1 faces can be distinctly traced.

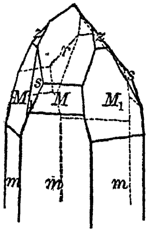

FIG. 261.

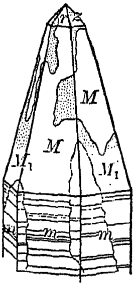

FIG. 262.

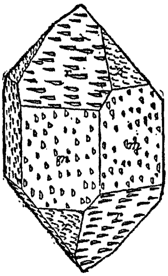

FIG. 263.

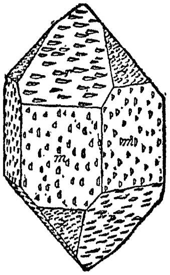

FIG. 264.

Judging from the outward form alone, quartz crystals like Figs. 253 and 254 would appear to have the same symmetry as crystals of the normal hexagonal type. This, however, is not the case, for if quartz crystals are subjected to the action of hydrofluoric acid artificial faces (corrosion or etching faces) are developed, which have a right- or left-handed distribution (Figs. 263 and 264), corresponding to that of the x faces on Figs. 256 and 257.

Orthorhombic System.

In this system the forms are referred to three axes a, b, and c at right angles to one another and of unequal lengths (Fig. 265). Any one of these may be chosen for the vertical axes c; the longer of the horizontal ones is then taken as b and is called the *macro-axis;* the shorter, as a and is called the *brachy-axis.* For each substance crystallizing in the system the ratio lengths of the axes must be determined from the measurement of appropriate angles. In sulphur, for example, the axial ratio is $a : b : c = 0.813 : 1 : 1.903$ (see p. 159).

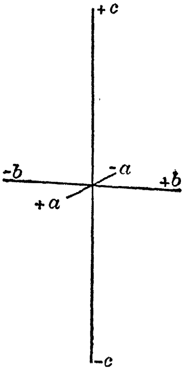

FIG. 265.

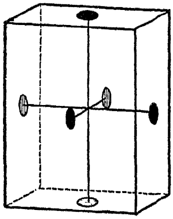

FIG. 266.

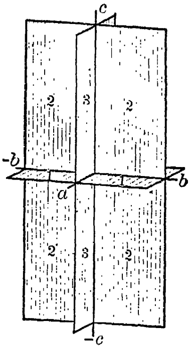

FIG. 267.

Forms of the Normal Group.—Barite Type.

The crystals of this group are characterized by having three axes of binary symmetry (Fig. 266) and three axial planes of symmetry (Fig. 267).

The forms are of three kinds, as follows: *pyramidal,* when the faces intersect the three axes; *prismatic,* when the faces intersect two axes and are parallel to the third; and *pinacoidal*, when the faces intersect one axis and are parallel to the other two.

Pyramids.—These consist of *eight similar faces*, and the form with the simplest symbol, *p* (111) (Fig. 268), is called the *unit pyramid.* In sulphur (Fig. 281) the form *p* (111) is shown in combination with a flatter pyramid *s* (113). Thus it will be noticed that on the same crystal there may be different pyramids, but under no condition can there be more than eight faces of the same kind.

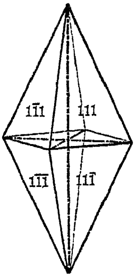

FIG. 268.

Prisms.—These consist of *four similar faces*, parallel to an axis; three kinds being possible, according as the faces are parallel to the *c*, the *b*, or the *a* axes.

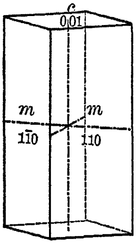

FIG. 269.

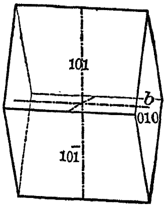

FIG. 270.

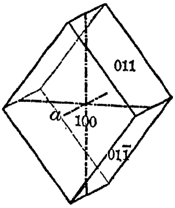

FIG. 271.

Vertical Prisms.—A prominent prism on a crystal is commonly assumed to be the form *m* (110), which is known as the *unit prism* (Fig. 269). This form is a right rhombic prism, its four faces being at right angles to the terminal face *c*, but never at right angles to one another, since the *a* and *b* axes are not of equal length.

Besides the unit prism, others may occur whose faces have such inclinations that they go from *a* to a multiple of *b*, or from *b* to a multiple of *a*, and are parallel to *c*. One of these is illustrated by topaz (Figs. 289 to 293), in which *l* is the prism (120).

Horizontal Prisms, or Domes.—When the prismatic forms are parallel to the horizontal axes they are conveniently designated as *domes*. Fig. 270 represents the form (101), known as the *macro-dome*, because it is parallel to the macro-axis *b* and Fig. 271, the form (011), called the *brachy-dome*, because it is parallel to the brachy-axis *a*. Each of the macro- and brachy-domes has *four similar faces*. Domes are common forms which, on crystals illustrating combinations in this system, will often appear at one of the extremities as *a pair of similar faces*. For example, the two triangular faces *r* at the extremity of Fig. 298 are planes of the macro-dome (101). In many instances the domes intercept the vertical axis at a multiple, or fraction, of its unit length, as illustrated by topaz (Figs. 290 to 293), in which the brachy-domes *f* and *y* have the symbols (021) and (041) respectively.

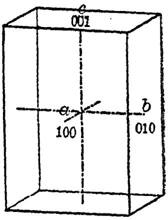

FIG. 272.

Pinacoids.—Three pinacoids are possible, each consisting of *two, similar, parallel faces*. These forms, represented in Fig. 272, are the *macro-pinacoid a* (100), the *brachy-pinacoid b* (010), and the *base* or *basal pinacoid c* (001). The faces of these three forms are at right angles to one another.

Combinations.—The following examples will illustrate the great variety of habits which may result from the combinations of pinacoids, prisms, domes, and pyramids. It should be noticed that the forms with simple indices, *a* (100), *b* (010), *c* (001), *m* (110), and *p* (111), are prominent. The position in which the crystals are placed (the crystallographic orientation) is to a certain extent arbitrary, since any one of the axes of symmetry may be taken for the vertical axis *c*.

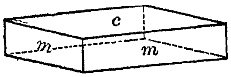

FIG. 273.

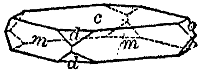

FIG. 274.

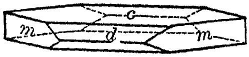

FIG. 275.

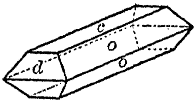

FIG. 276.

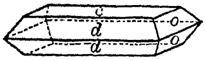

FIG. 277.

Barite (Figs. 273 to 277).—Axes $a : b : c = 0.815 : 1 : 1.314$. Angles $m \wedge m = 78° 22'$ and $c \wedge o = 52° 43'$. The crystals commonly have the basal plane *c* prominent and are, therefore, tabular. The prism *m* (110), the macro-dome *d* (102), and the brachy-dome *o* (011) are generally present.

Celestite (Figs. 278 and 279) —Axes $a : b : c = 0.779 : 1 : 1.280$. Angles $m \wedge m = 75° \ 50'$ and $c \wedge o = 52° \ 0'$. The crystals are often tabular like Figs. 273 to 275 of barite, and often they are lengthened out in the direction of the brachy-axis, having the brachy-dome *o* (011) prominent (Fig. 279). The prism *m* (110) and the macro-dome *d* (102) are generally present, while *l* (104) occurs occasionally (Fig. 278).

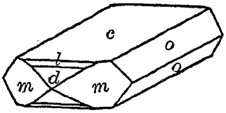

FIG. 278.

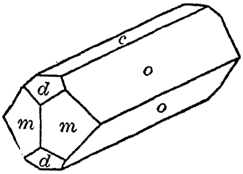

FIG. 279.

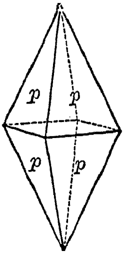

FIG. 280.

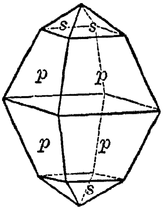

FIG. 281.

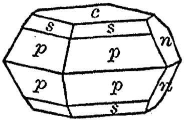

FIG. 282.

Sulphur (Figs. 280 to 282).—Axes $a : b : c = 0.813 : 1 : 1.903$ Angles $m \wedge m = 78° \ 14'$ and $c \wedge n = 62° \ 17'$. A pyramidal habit, *p* (111), is common, often with the apex truncated by the pyramid *s* (113) or the base *c*. The brachy-dome *n* (011) is also often present.

Stibnite (Figs. 283 and 284).—Axes $a : b : c = 0.992 : 1 : 1.018$. Angles $m \wedge m = 89° \ 34'$ and $c \wedge p = 55° \ 19$. The crystals are prismatic, with the prism *m* (110) and the brachy-pinacoid *b* (010) prominent. They are often long and slender, and are generally terminated by the pyramidal forms *p* (111), *s* (113), and *τ* (343).

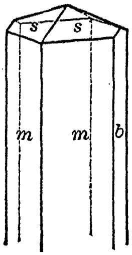

FIG. 283.

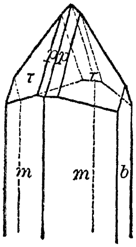

FIG. 284

Arsenopyrite (Figs. 285 and 286).—Axes $a : b : c = 0.677 : 1 : 1.188$. Angles $m \wedge m = 68^\circ\ 13'$ and $c \wedge q = 49^\circ\ 55'$. A short prism *m* (110), terminated by the brachy-dome *u* (014), is the common habit. The brachy-dome *q* (011) terminating the prism is occasionally met with.

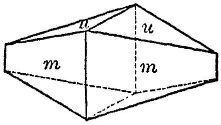

FIG. 285.

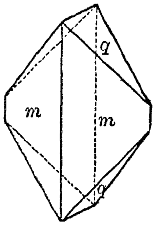

FIG. 286.

Chalcocite (Figs. 287 and 288).—Axes $a : b : c = 0.582 : 1 : 0.970$. Angles $m \wedge m = 60^\circ\ 25'$ and $c \wedge d = 62^\circ\ 44'$. The crystals are commonly flat, with a striated basal plane *c* (001) and the brachy-dome *d* (021) prominent. The prism *m* (110), two pyramids *p* (111) and *v* (112), and the brachy-pinacoid *b* (010) are common forms. Twin

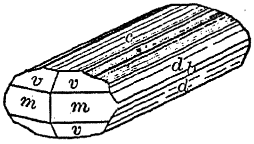

FIG. 287.

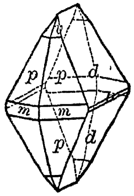

FIG. 288.

crystals are very common, and frequently imitate forms of the hexagonal system, as will be explained under aragonite (p. 206).

Topaz (Figs. 289 to 293). — Axes $a : b : c = 0.528 : 1 : 0.477$. Angles $m \wedge m = 55^\circ\ 43'$ and $c \wedge p = 45^\circ\ 35'$. The crystals are generally prismatic, with two prisms developed, m (110) and l (120).

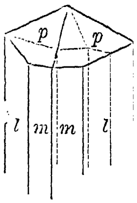

FIG. 289.

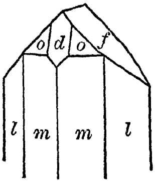

FIG. 290.

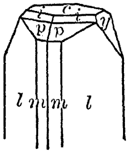

FIG. 291.

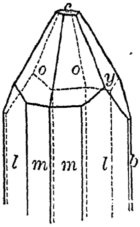

FIG. 292.

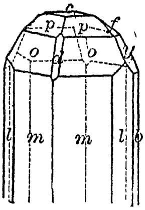

FIG. 293.

The forms which usually occur at the terminations are the base c, the brachy-domes f (021) and y (041), the macro-dome d (201), and the pyramids o (221), p (111), and i (223). Doubly terminated crystals are rather exceptional.

Chrysolite (Figs. 294 to 296).—Axes $a : b : c = 0.466 : 1 : 0.586$. Angles $m \wedge m = 49^\circ\ 57'$ and $c \wedge p = 54^\circ\ 15'$. In the vertical zone the pinacoids a (100) and b (010) and the prism m (110) are usually present, and occasionally, also, a second prism s (120). The crystals

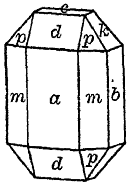

FIG. 294.

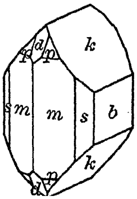

FIG. 295.

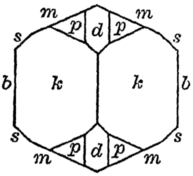

FIG. 296.

are terminated by the brachy-dome *k* (021), the macro-dome *d* (101), the pyramid *p* (111), and occasionally, the basal plane *c* (001). Fig. 296 is a basal projection of Fig. 295, which shows the symmetrical development of the orthorhombic forms when viewed in the direction of the vertical axis.

Staurolite (Figs. 297 to 300).—Axes $a : b : c = 0.473 : 1 : 0.683$. Angle $m \wedge m = 50° 40'$. The crystals are generally prismatic, with the prism *m* (110) and the brachy-pinacoid *b* (010) developed. They are terminated either by the base *c* (001), or a combination of *c* and the macro-dome *r* (101). Penetration twins are very common; the prisms crossing either at nearly 90° when a brachy-dome (032) is the twinning-plane, or at nearly 60° when a pyramid $(\bar{2}32)$ is the twinning-plane.

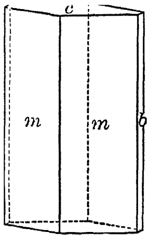

FIG. 297.

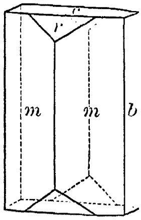

FIG. 298.

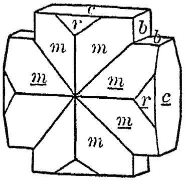

FIG. 299.

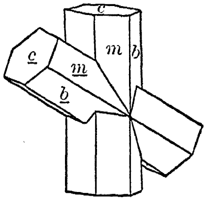

FIG. 300.

Aragonite (Figs. 301 to 307).—Axes $a : b : c = 0.662 : 1 : 0.721$. Angles $m \wedge m = 63° 48'$ and $c \wedge k = 35° 47'$. Slender, needle-like crystals, either tapering to a point or with well-defined faces (usually the brachy-dome *k* (011)) at the extremity, are common

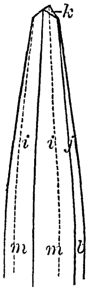

FIG. 301.

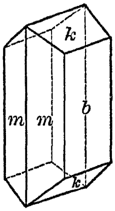

FIG. 302.

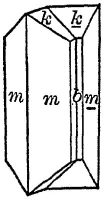

FIG. 303.

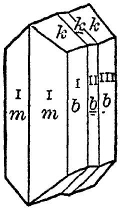

FIG. 304.

(Fig. 301). The indices of the steep pyramid *i* (661) and the brachy-dome *j* (0.12.1) are uncertain. Simple crystals (Fig. 302) showing the combination of the prism *m*, the brachy-pinacoid *b*, and the brachy-dome *k* are exceptional; while twins (Fig. 303), often polysynthetic (Fig. 304), are more often observed, the prism *m* (̄110) being the twinning-plane. A complex method of twinning and intergrowth is common, from which a form resembling a hexagonal prism results. The character of these *apparently hexagonal* crystals may be explained as follows: The cross-section of a simple crystal like Fig. 302 is represented by Fig. 305. Three individuals I, II, and III (Fig. 306), each striated parallel to the brachy-axis, and crystallizing with their prismatic faces *m* as the twinning-planes, would diverge at angles of about 120°. Provided that each crystal *penetrated* beyond the center, a six-sided form would result, with the individuals meeting along the somewhat irregular lines of interpenetration (Fig. 307). The complex character of such twins is generally revealed by striations on the basal planes, diverging as represented in Fig. 307, and also by small re-entrant angles.

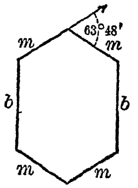

FIG. 305.

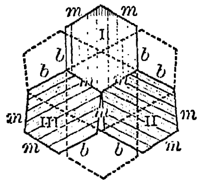

FIG. 306.

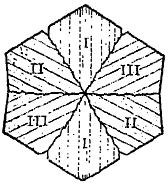

FIG. 307.

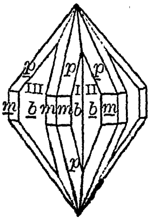

FIG. 308.

There is a tendency in a number of minerals having a prismatic angle of nearly 60°, to occur in complex twin crystals like those of aragonite, which *imitate* forms of the hexagonal system.

Cerussite (Fig. 308).—Axes $a : b : c = 0.610 : 1 : 0.723$. Angle $m \wedge m = 62° \ 46'$. The figure represents a form with deep re-entrant angles, resulting from the penetration of three individuals in twin position. (Compare Figs. 306 and 307 of aragonite.) Each crystal has the brachy-pinacoid *b* (010) prominent, in combination with the prism *m* (110) and the pyramid *p* (111). Occasionally twin crystals of cerussite occur without the re-entrant angles, when they may appear like a combination of the pyramid and prism of the hexagonal system.

Childrenite (Fig. 309).—Axes $a : b : c = 0.778 : 1 : 0.526$. Angle $m \wedge m = 75° 46'$. This example has been introduced to illustrate the combination of a pyramid *s* (121) in combination with the pinacoids *a* (100) and *b* (010).

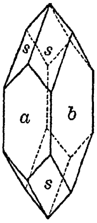

FIG. 309.

ORTHORHOMBIC FORMS OF LOWER SYMMETRY THAN THAT PRESENTED BY THE NORMAL GROUP.

Hemimorphic Group.—Calamine Type.

The crystals of this group are characterized by having one axis of binary symmetry and two planes of symmetry. The peculiarity of the crystals is that the forms at opposite extremities of the axis of symmetry are not alike.

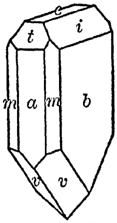

FIG. 310.

Calamine (Fig. 310).—Axes $a : b : c = 0.783 : 1 : 0.478$. Angle $m \wedge m = 76° 9'$. The combination of the macro-pinacoid *a* (100), the brachy-pinacoid *b* (010), and the prism *m* (110), is terminated above by the base *c* (001) and the brachy- and macro-domes *i* (031) and *t* (301), while below the pyramid *v* $(12\bar{1})$ occurs.

Sphenoidal Group.—Epsomite Type.

Crystals of this group are characterized by having three axes of binary symmetry and no planes of symmetry.

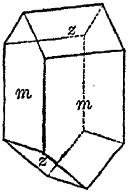

FIG. 311.

Epsomite (Fig. 311).—Axes $a : b : c = 0.990 : 1 : 0.571$. Angle $m \wedge m = 89° 26'$. The figure represents the prism *m* (110), terminated above and below by two faces of the form *z*, having the symbol (111). The four *z* faces alone produce a form known as a *sphenoid*, similar to Fig. 65, p. 164. The faces correspond in their axial relations to the alternating planes of the orthorhombic pyramid (111) of the normal group.

MONOCLINIC SYSTEM.

In this system the forms are referred to three axes, a, b and c of unequal lengths, with a and c intersecting at an acute angle β behind, while b is at right angles to a and c (Fig. 312). The axis *b* is called the *ortho-axis*, because it is at right angles to the other two; and *a* is called the *clino-axis*, because it is inclined to the *vertical axis c*. For each substance crystallizing in this system the ratio lengths of the axes and the axial inclination β must be determined from the measurement of appropriate angles. For gypsum the axial relation is $a : b : c = 0.690 : 1 : 0.412$; $\beta = 80° \ 42'$.

Forms of the Normal Group.—Gypsum Type.

The crystals of this group are characterized by having one axis of binary symmetry (Fig. 313), which is always taken as the crystallographic axis *b*, and one plane of symmetry. The plane of symmetry (Fig. 314) is always supposed to occupy a vertical position, and the *a* and *c* axes are located in it.

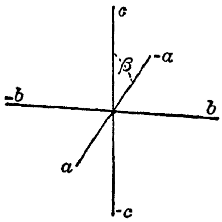

FIG. 312.

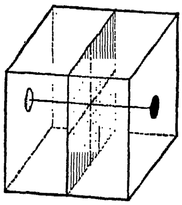

FIG. 313.

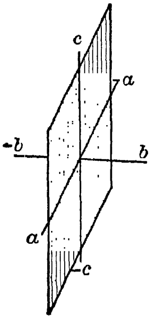

FIG. 314.

Monoclinic forms are of two kinds; either *prismatic* with four similar faces, or *pinacoidal* with two parallel faces. It is convenient, however, to designate the forms according to their relation on the axes: as *pyramids*, when the faces intersect all three axes; *prisms* or *domes*, when they intersect two axes and are parallel to one; and *pinacoids*, when they intersect one axis and are parallel to the other two.

Pyramids.—The form (111) (Fig. 315) consists of *four similar faces*. These four faces really constitute a *prism* with its edges parallel to the direction $a : c$. The name pyramid is simply one of convenience for designating the particular kind of form which intersects the three axes. A somewhat similar, but different, and entirely independent form is ($\bar{1}11$) (Fig. 316), also consisting of four similar faces. The solid represented by Fig. 317 is a combination of the two independent forms p (111) and o ($11\bar{1}$). It should be distinctly understood that no form in this system is more complicated than the ones just explained. The symbol may be less simple, for example (321), but the symmetry demands the existence of only four faces of the same kind.

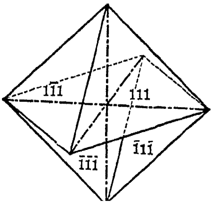

FIG. 315.

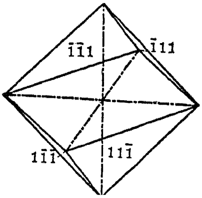

FIG. 316.

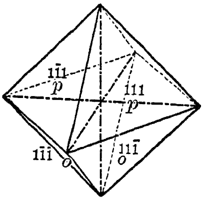

FIG. 317.

Prisms.—A prismatic form, consisting of *four similar faces* is commonly taken as the *unit-prism* m (110) (Fig. 318). Such a form is an *inclined prism*, the two faces in front making equal angles with the terminal face c, but not angles of 90°. Besides

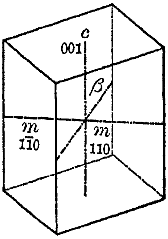

FIG. 318.

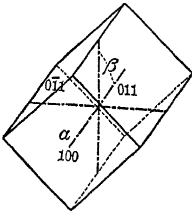

FIG. 319.

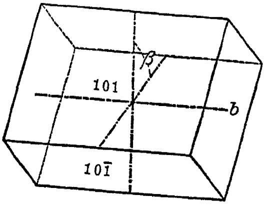

FIG. 320.

the prism (110) others occur, whose faces are so inclined that they go from *a* to a multiple of *b*, or from *b* to a multiple of *a*, and are parallel to *c*. Two prisms, *m* (110) and *z* (130), often occur on orthoclase (Fig. 328).

Domes.—The form (011) (Fig. 319) has *four similar faces* which make an inclined prism. It is convenient to designate this form, however, as a *clino-dome*, so named because the faces are parallel to the clino-axis *a*.

Owing to the symmetry of monoclinic crystals the form (101) occurs as *a pair of similar faces.* Fig. 320 represents two independent forms (101) and (10$\bar{1}$), called *ortho-domes*, in combination with a terminal face *b*.

Pinacoids.—There are three forms, each consisting of *two parallel faces* (Fig. 321), which are especially important: the *ortho-pinacoid a* (100), the *clino-pinacoid b* (010), and the *base* or *basal pinacoid* *c* (001). The clino-pinacoid *b*, which is parallel to the symmetry plane (Fig. 313), is at right angles to both the base *c* and the ortho-pinacoid *a*, while the two latter forms make an angle with one another which is equal to the axial inclination β.

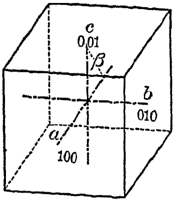

FIG. 321.

Combinations.—The following examples will illustrate some of the various habits which may result from the combination of monoclinic forms, and it should be noticed that it is possible in almost all cases, to orientate the crystals so that the symbols of their forms can be expressed by very simple indices. The prevailing forms are the pinacoids *a* (100), *b* (010), and *c* (001), the prism *m* (110), and the pyramid *p* (111).

Gypsum (Figs. 322 to 325).—Axes $a : b : c = 0.690 : 1 : 0.412$; $\beta = 80° 42'$. Angles $m \wedge m = 68° 30'$ and $p \wedge p = 36° 12'$. Crystals usually have the clino-pinacoid *b* (010) prominent, in combination with the prism *m* (110) and the pyramid *p* (111). The ortho-dome *e* ($\bar{1}$03) is often present. Twins are common, with the ortho-pinacoid (100) as the twinning-plane (Fig. 325).

The arbitrary method of orientating a monoclinic crystal and naming the forms is here brought to notice. The four faces of the so-called pyramid *p*, if placed vertically, could have been taken as the prism (110), when the *m* faces would most naturally be taken as the clino-dome (011). A crystal of gypsum thus orientated would, of course, have a different axial ratio than the one given above. The only form on monoclinic crystals which is actually determined by the symmetry is the clino-pinacoid *b* (010).

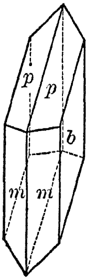

FIG. 322.

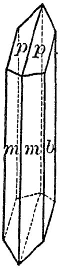

FIG. 323.

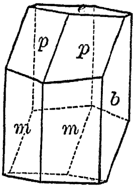

FIG. 324.

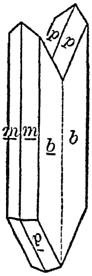

FIG. 325.

Orthoclase (Figs. 326 to 329).—Axes $a : b : c = 0.658 : 1 : 0.555$; $\beta = 63° 57'$. Angles $m \wedge m = 61° 13'$, $c \wedge x = 50° 16'$, and $c \wedge y = 80° 18'$. The prominent forms are the prism *m* (110) and the pinacoids *b* (010) and *c* (001). A second prism *z* (130), the ortho-domes *x* $(\bar{1}01)$ and *y* $(\bar{2}01)$, and the pyramid *o* $(\bar{1}11)$, are often present. A common kind of twinning consists of two individuals united with their *b* faces in common (Fig. 329). The twinning-axis is the vertical axis *c*. On the crystal in the normal position the base *c* slopes toward the front, while in the twinned individual it slopes toward the back.

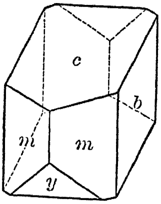

FIG. 326.

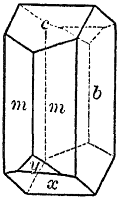

FIG. 327.

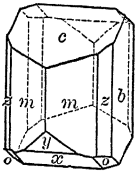

FIG. 328.

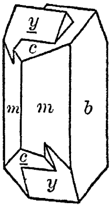

FIG. 329.

Pyroxene (Figs. 330 to 336).—Axes $a : b : c = 1.092 : 1 : 0.589$; $\beta = 74° 10'$. Angles $m \wedge m = 92° 50'$, $p \wedge p = 48° 29'$, and $s \wedge s =$

59° 11′. Prismatic crystals are common, the prisms *m* (110) being stout, nearly rectangular ($m \wedge m = 92^\circ 50'$), and generally truncated by the ortho-pinacoid *a* (100) and the clino-pinacoid *b* (010). The crystals are variously terminated; the prevailing forms being the base *c* (001), the ortho-domes *d* $(\bar{1}01)$ and *n* $(\bar{1}02)$, and the pyramids *p* (111), *v* (221), *s* $(\bar{1}11)$, and *o* $(\bar{2}21)$. Fig. 334 is a basal projection of Fig. 333, and shows the symmetrical development of the monoclinic forms on either side of the symmetry plane, intersecting the crystal parallel to the face *b*. Figs. 335 and 336 represent the ordinary development of crystals of augite, a variety of pyroxene common in volcanic rocks.

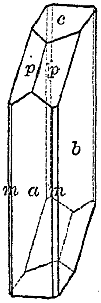

FIG. 330.

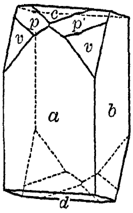

FIG. 331.

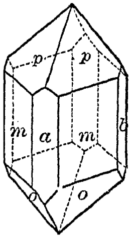

FIG. 332.

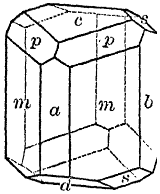

FIG. 333.

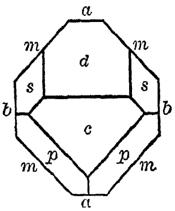

FIG. 334.

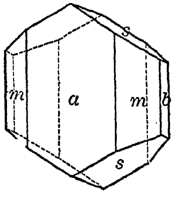

FIG. 335.

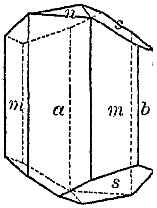

FIG. 336.

Amphibole (Figs. 337 to 339).—Axes $a : b : c = 0.551 : 1 : 0.294$; $\beta = 73^\circ 58'$. Angles $m \wedge m = 55^\circ 49'$ and $r \wedge r = 31^\circ 32'$. The crystals are commonly long and bladed, with the prism *m* (110) prominent, or apparently hexagonal ($m \wedge m =$ nearly 60°), when *m* and the clino-pinacoid *b* are about equally developed. A second prism *e* (130) and the ortho-pinacoid *a* (100) are often present. The crystals are generally terminated by the faces of the clino-dome *r* (011).

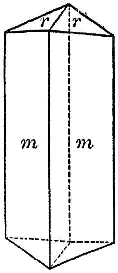

FIG. 337.

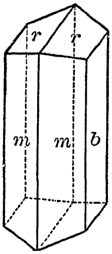

FIG. 338.

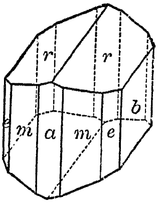

FIG. 339.

Titanite or *Sphene* (Figs. 340 to 342).— Axes $a : b : c = 0.755 : 1 : 0.854$; $\beta = 60° 17'$. Angles $m \wedge m = 66° 29'$, $p \wedge p = 43° 49'$, and $c \wedge p = 38° 16'$. The prism m (110) and the pyramid p (111) are generally prominent, and in combination with the base c (001) and the ortho-pinacoid a (100). The very obtuse interfacial angles of Fig. 341 are conspicuous, from which the name *sphene*, meaning a *wedge*, is derived.

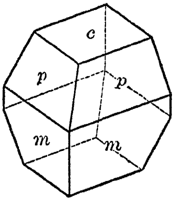

FIG. 340.

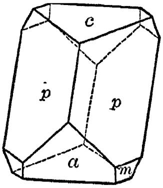

FIG. 341.

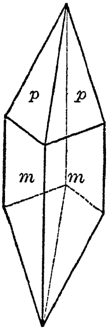

FIG. 342.

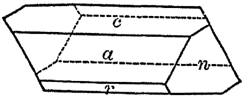

FIG. 343.

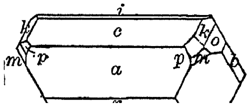

FIG. 344.

Epidote (Figs 343 and 344).—Axes $a : b : c = 1.578 : 1 : 1.804$; $\beta = 64° 37'$. Angles $m \wedge m = 109° 56'$, $n \wedge n = 70° 29'$, and $c \wedge r = 63° 42'$. The crystals of epidote generally have a somewhat unusual development, being long in the direction of the symmetry-axis, owing to the prominence of the base c (001), the ortho-pinacoid *a* (100), and the ortho-domes *r* ($\bar{1}01$) and *i* ($\bar{1}02$). At the ends, the pyramid *n* ($\bar{1}\bar{1}1$) is generally the most prominent form, while the other forms shown in Fig. 344 are the clino-pinacoid *b*, the clino-domes *o* (011) and *k* (012), the prism *m* (110), and the pyramid *p* (111).

MONOCLINIC FORMS OF LOWER SYMMETRY THAN THAT PRESENTED BY THE NORMAL GROUP.

Two groups are recognized, but are, however, very rarely observed. One is *hemimorphic*, having an axis of binary symmetry but no plane of symmetry; the other has a plane of symmetry, but no axis of symmetry.

TRICLINIC SYSTEM.

In this system the forms are referred to three axes, a, b, and c, of unequal lengths, and intersecting at oblique angles, α, β, and γ (Fig. 345). The directions which are taken to represent the axes correspond to prominent crystallographic features, but otherwise are arbitrarily chosen. Any one of the axes may be taken as the vertical axis *c*, and of the lateral ones, *b* is the longer or *macro-axis* and *a* the shorter or *brachy-axis*. For each mineral crystallizing in this system, the ratio lengths of the axes and the inclinations α, β, and γ must be determined from the measurement of appropriate angles. In axinite, for example, $a:b:c = 0.492:1:0.480$; and $\alpha = 82° 54'$, $\beta = 91° 52'$, and $\gamma = 131° 32'$.

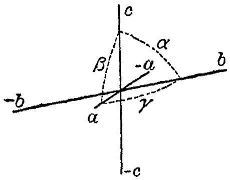

FIG. 345.

Forms of the Normal Group.—Axinite Type.

Crystals of this group have a center of symmetry, but neither planes nor axes of symmetry. Each form consists of *two similar parallel faces*, diametrically disposed with reference to a central point.

Each form, since it consists of only two parallel faces, has the character of a *pinacoid*. It is convenient, however, to designate the forms according to their relations on the axes, as *pyramids* when they intersect the three axes, as *prisms* or *domes* when they intersect two axes and are parallel either to the vertical or to one of the horizontal axes, and as *pinacoids* when they intersect one axis and are parallel to the other two.

Pyramids.—The form (111) (Fig. 346) consists of *two similar faces*, and is designated as a pyramid for the sake of convenience. Four entirely different forms are possible, each of which intersects the axes at their unit lengths, (111), $(1\bar{1}1)$, $(11\bar{1})$, and $(1\bar{1}\bar{1})$ (Fig. 347).

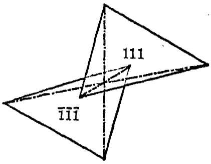

FIG. 346.

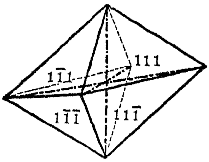

FIG. 347.

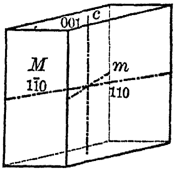

FIG. 348.

No single form can be more complex than the one represented by Fig. 346. The symbol may be more complicated, for example (321), but the form can consist of but two faces.

Prisms.—The forms *m* (110) and *M* $(1\bar{1}0)$ (Fig. 348) each consists of *two similar faces*, and the four planes constitute a triclinic prism, whose faces do not make equal angles with the terminal plane *c*.

Domes.—If the forms are parallel to the *b* axis, for example, (101) or $(10\bar{1})$ (Fig. 349), they are called *macro-domes*; and if parallel to the *a* axis, for example, (011) or (011) (Fig. 350), they are called *brachy-domes*.

Pinacoids.—When it is reasonable to do so, it is customary to select three prominent faces of a crystal to represent the *macro-pinacoid a* (100), the *brachy-pinacoid b* (010), and the *base* or *basal pinacoid c* (001) (Fig. 351). These three forms are important, because their intersections determine the axial directions.

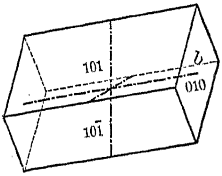

FIG. 349.

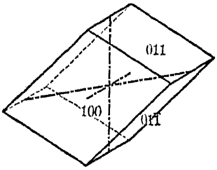

FIG. 350.

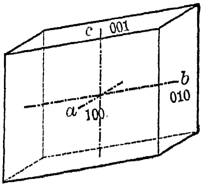

FIG. 351.

Combinations.—The following illustrations will serve to show some of the variations in habit which may result from the combination of triclinic forms. Since the crystals have neither a plane nor an axis of symmetry, any face may be taken as a pyramid, prism, dome, or pinacoid. In orientating a triclinic crystal the most important thing to be considered is the adoption of such a position that the prominent faces will have as simple indices as possible. It should be noticed, in studying the examples given below, that the crystals have been so orientated that, in most cases, the prominent forms are the pinacoids a (100), b (010), and c (001), and the prisms m (110) and M $(1\bar{1}0)$, all having very simple indices.

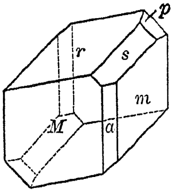

FIG. 352.

Axinite (Fig. 352). — Axes $a : b : c = 0.492 : 1 : 0.480$; $\alpha = 82° \ 54'$, $\beta = 91° \ 52'$, and $\gamma = 131° \ 32'$. Angles $a \wedge m = 15° \ 34'$, $a \wedge M = 28° \ 55'$, $m \wedge p = 30° \ 33'$, and $M \wedge r = 45° \ 15'$. Prominent forms are the two prisms m (110) and M $(1\bar{1}0)$, terminated by the pyramids p (111) and r $(1\bar{1}1)$, and the macro-dome s (201). The exceptionally acute and obtuse angles of the crystal are conspicuous, whence the name axinite (*ἀξίνη, an axe*).

Albite (Figs. 353 to 356).—Axes $a : b : c = 0.633 : 1 : 0.558$; $\alpha = 94° \ 3'$, $\beta = 116° \ 29'$, and $\gamma = 88° \ 9'$. Angles $b \wedge c = 86° \ 24'$, $m \wedge c = 65° \ 18'$, $M \wedge c = 69° \ 10'$, and $m \wedge M = 59° \ 14'$. The crystals are commonly flat (tables) with the brachy-pinacoid b (010) prominent. Combined with this are the two prisms m (110) and M $(1\bar{1}0)$, the base c (001), and the macro-dome x $(\bar{1}01)$. The pyramids o $(11\bar{1})$ and q $(1\bar{1}\bar{1})$ are often present. Twins are common, often polysyn-

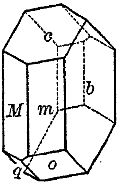

FIG. 353.

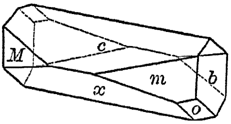

FIG. 354.

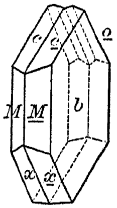

FIG. 355.

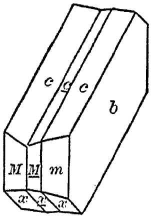

FIG. 356.

thetic (Fig. 356), the pinacoid *b* being the twinning-plane. The basal planes of polysynthetic crystals show a repetition of re-entrant and salient angles; and when the lamellæ are numerous, as is often the case, the basal plane, or cleavage-surface, shows a series of fine striations (Fig. 87, p. 168). The similarity between albite and the closely related mineral orthoclase of the monoclinic system (p. 211), may be seen by comparing their axial ratios and interfacial angles.

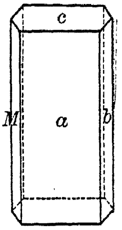

Fig. 357.

Cyanite (Fig. 357).—Axes $a : b : c = 0.899 : 1 : 0.709$; $\alpha = 90° 5'$, $\beta = 101° 2'$, and $\gamma = 105° 44'$. Angles $a \wedge b = 73° 56'$, $a \wedge c = 78° 30'$, $b \wedge c = 86° 45'$, and $a \wedge M = 48° 18'$. The crystals are generally long and bladed, owing to the prominence of the macro-pinacoid *a* (100), and are seldom terminated by distinct faces.

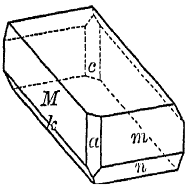

Fig. 358.

Rhodonite, variety *Fowlerite* (Fig. 358).—Axes $a : b : c = 1.078 : 1 : 0.626$; $\alpha = 103° 39'$, $\beta = 108° 48'$, and $\gamma = 81° 55'$. Angles $c \wedge a = 72° 30'$, $a \wedge m = 48° 33'$, $m \wedge M = 92° 49'$, $c \wedge m = 68° 25'$, and $c \wedge M = 86° 41'$. The crystals are commonly somewhat tabular, with the base *c* (001) prominent. The two prisms *m* (110) and *M* (1$\bar{1}$0) are common, while the pyramids *n* (22$\bar{1}$) and *k* (2$\bar{2}\bar{1}$) are usually subordinate. Rhodonite ($m \wedge M = 92° 49'$) is closely related to pyroxene (p. 210), in which $m \wedge m = 92° 50'$.

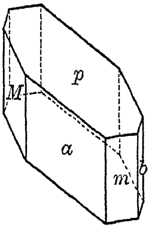

Fig. 359.

Chalcanthite (*Blue Vitriol*) (Fig. 359).—Axes $a : b : c = 0.566 : 1 : 1.055$; $\alpha = 82° 21'$, $\beta = 73° 11'$, and $\gamma = 77° 37'$. Angles $a \wedge b = 100° 41'$, $a \wedge m = 30° 51'$, $a \wedge M = 25° 59'$, and $m \wedge p = 52° 20'$. The crystals commonly have the two pinacoids *a* (100) and *b* (010) and the two prisms *m* (110) and *M* (1$\bar{1}$0) prominent, and are terminated by the faces of the pyramid *p* (111).

TRICLINIC FORMS OF LOWER SYMMETRY THAN THAT PRESENTED BY THE NORMAL TYPE.

Triclinic crystals have been observed which do not have a center of symmetry, but no minerals belonging to this class are known. On the crystals, each form consists of a single plane, but the occurrence of any crystal face does not necessitate the existence of one parallel to it.

Note Concerning the Systems of Crystallization.

Although crystals are classified into six systems, according to their axial relations, each system is subdivided into groups with varying degrees or kinds of symmetry. Each of these subdivisions really constitutes a *distinct class*, characterized by a *particular kind of symmetry*, which a substance crystallizing in that class *will invariably show*. From purely mathematical considerations it can be shown that there are *thirty-two possible classes* to which crystals can be referred, and all but three of them have been observed either among minerals or artificially crystallized salts.

The possible kinds of symmetry are shown in the table opposite. The references will serve to indicate the important classes which have been described in the foregoing pages.

Pseudomorphous Crystals.

Although the occurrence of a mineral in distinct crystals may generally be regarded as a proof of the homogeneous character and purity of the material (p. 156), this is not always the case. A substance may either undergo chemical alteration or be replaced by material of entirely different character without perceptible change in the crystalline form, and thus crystals result which have the form of one mineral and the chemical composition of another. Such crystals are known as *pseudomorphs* (ψευδής, *false*, and μορφή, form).

TABLE SHOWING THE SYMMETRY OF THE THIRTY-TWO CLASSES OF CRYSTALS.

An asterisk denotes the absence of a Center of Symmetry.

System.	Class.	Group.	Planes of Symmetry.	Axes of Symmetry. ⬢ Hexagonal. ◆ Tetragonal. ▲ Trigonal. ⬬ Binary.	Greatest Number of Similar Faces Possible on a Crystal, with Reference.
Isometric.	1	Normal	9	3 ◆ 4 ▲ 6 ⬬	48. Hexoctahedron, Fig. **113**
	2	Pyritohedral	3	3 ⬬ 4 ▲	24. Diploid, Fig. 118
	3	Tetrahedral*	6	3 ⬮ 4 ▲	24. Hexakistetrahedron, F. 132
	4	*...............	0	3 ◆ 4 ▲ 6 ⬬	24. Rare, cuprite
	5	*...............	0	3 ⬮ 4 ▲	12. Rare, langbeinite
Hexagonal.	6	Normal	7	1 ⬢ 6 ⬬	24. Dihexagonal pyr., F. **193**
	7	Hemimorphic*	6	1 ⬢	12. Rare (p. 190)
	8	Tri-pyramidal	1	1 ⬢	12. The *μ* faces, Fig. 207
	9	*...............	0	1 ⬢ 6 ⬬	12. Rare, artificial salts
	10	*...............	0	1 ⬢	6. Rare, nephelinite
Hexagonal-rhombohedral.	11	....	4	1 ▲ 3 ⬬	12. Unknown
	12	Normal	3	1 ▲ 3 ⬬	12. Scalenohedron, Fig. 217
	13	Hemimorphic*	3	1 ▲	6. The *u* faces, Fig. 247
	14	Tri-rhombohedral	0	1 ▲	6. Rhombohedron. The *x* faces, Fig. 248
	15	Trapezohedral*	0	1 ▲ 3 ⬬	6. Trapezohedron, Figs. 258 and 259
	16	*...............	1	1 ▲	6. Unknown
	17	*	0	1 ▲	3. Rare, artificial salt
Tetragonal.	18	Normal	5	1 ◆ 4 ⬬	16. Ditetragonal pyr., F. **146**
	19	*...............	4	1 ◆	8. Rare, artificial salts
	20	Tri-pyramidal	1	1 ◆	8. The *s* faces, Fig. 173
	21	Sphenoidal*	2	1 ⬮ 2 ⬮	8. The *χ* faces, Fig. 185
	22	*...............	0	1 ◆ 4 ⬬	8. Rare, artificial salts
	23	*...............	0	1 ◆	4. Rare, wulfenite
	24	*...............	0	1 ⬮	4. Unknown
Ortho-rhombic.	25	Normal	3	3 ⬬	8. Pyramid, Fig. 268
	26	Hemimorphic*	2	1 ⬬	4. The *v* faces, Fig. 310
	27	Sphenoidal*	0	3 ⬮	4. The *z* faces, Fig. 311
Mono-clinic	28	Normal	1	1 ⬬	4. The *p* faces, Fig. 322
	29	*...............	0	1 ⬬	2. Rare, artificial salts
	30	*..............	1	None	2. Rare, clinohedrite
Tri-clinic.	31	Normal	0	None	2. The *p* faces, Fig. 352
	32	*............ ..	0	None	1. Rare, artificial salt

Pseudomorphs by Chemical Alteration of the Original Material.—Crystals of pyrite, FeS_2, by long exposure may become oxidized and hydrated, and partly or wholly converted into limonite (iron rust), $Fe_4O_3(OH)_6$. Thus *pseudomorphs of limonite after pyrite* are formed. A similar change takes place when iron *rusts* from exposure. If a discarded rusty tool is found, the character of the implement may generally be determined from the shape of the mass of iron rust, even though the steel has wholly disappeared, and so, from the shape of a pseudomorphous crystal, the nature and name of the original mineral may generally be inferred. Other illustrations are the change by hydration and loss or gain of magnesium oxide, of the silicates chrysolite, Mg_2SiO_4, and enstatite, $MgSiO_3$, to serpentine, $H_4Mg_3Si_2O_9$.

$$2Mg_2SiO_4 + 2H_2O \textit{ less } MgO = H_4Mg_3Si_2O_9.$$
$$2MgSiO_3 + 2H_2O \textit{ plus } MgO = H_4Mg_3Si_2O_9.$$

Pseudomorphs by Incrustation and Replacement.—Often crystals of fluorite become coated with quartz, and subsequently the former is removed by solution or other agency, and the space thus left vacant is wholly or partly filled by a deposit of quartz, thus producing *pseudomorphs of quartz after fluorite.* Another illustration is furnished by petrified wood. As the wood decays the silica which is dissolved in the percolating water is deposited upon its fibers, often preserving the delicate structure of the wood in a remarkable manner.

Pseudomorphs Resulting from Molecular Change.—When molten sulphur is cooled, rather quickly, crystals belonging to the monoclinic system are formed, which cannot be preserved at ordinary temperatures, because they undergo a *molecular change* to the orthorhombic modification (p. 202). Similar changes in molecular condition, without the addition or removal of chemical constituents, take place in nature, giving rise to *pseudomorphs of calcite after aragonite, rutile after brookite, amphibole after pyroxene*, etc. These are also called *paramorphs.*

STRUCTURE OF MINERALS.

In describing the structure of minerals a number of terms are conveniently employed which will need a little explanation.

Granular.—When a mineral consists of an aggregate of crystalline particles of about the same size, as marble and some varieties of galena.

Compact.—Earthy.—A more or less firm consistency, resulting from a uniform aggregation of exceedingly minute particles, as kaolin (clay).

Massive.—When a substance exhibits no crystal faces, although it may possess a crystalline structure. Massive materials (pieces of quartz, chalcopyrite, etc.) are more often encountered than well-crystallized specimens.

Amorphous.—When *no trace* of crystalline structure exists. There are not many minerals which are truly amorphous, and they are not always easily distinguished from massive materials. Opal, amber, and obsidian (volcanic glass) are good examples.

Columnar.—When there is a parallel, or nearly parallel, grouping of prisms or columns, as illustrated by some varieties of wollastonite and beryl.

Fibrous.—A structure similar to the foregoing, but in which the individuals are exceedingly minute, as illustrated by some varieties of serpentine (Fig. 360), amphibole (variety asbestus), and gypsum. The fibers may often be separated or pulled apart into fine shreds. Minerals possessing a fine fibrous structure usually have a silky luster; hence fibrous gypsum is called *satin-spar*.

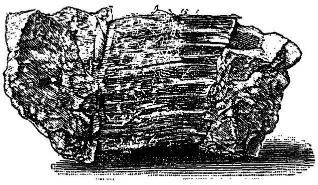

FIG. 360.
Fibrous Structure.—Serpentine.

Foliated.—When a mineral separates easily into plates, as in some varieties of serpentine and brucite.

Micaceous.—A structure similar to the foregoing, but in which the material can be split readily into exceedingly thin sheets, as muscovite (common mica).

Radiated.—When columns, fibers, or foliæ diverge from central points, as in pectolite (Fig. 361), wavellite, and pyrophyllite.

Reniform and Mammillary.—These are terms applied to rounded masses, usually with a smooth exterior, which have a resemblance either to a kidney or to mammæ. They are illustrated by some varieties of hematite (Fig. 362) and malachite.

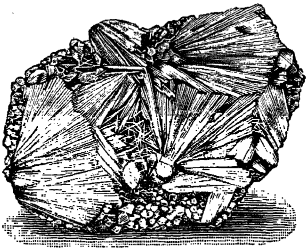

Fig. 361.
Radiated Structure.—Pectolite.

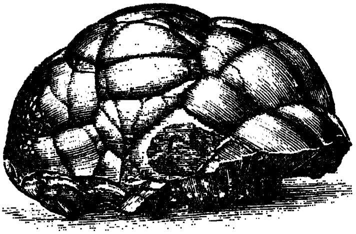

Fig. 362.
Reniform Structure.—Kidney-iron or Hematite.

Botryoidal and Globular.—These terms are applied to rather small rounded or spherical prominences, found in some varieties of smithsonite (Fig. 363), opal (hyalite) and other minerals.

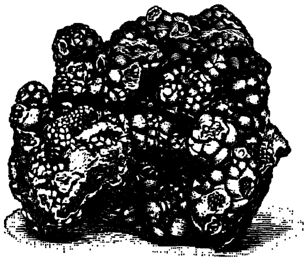

Fig.
Botryoidal Structure.—Smithsonite.

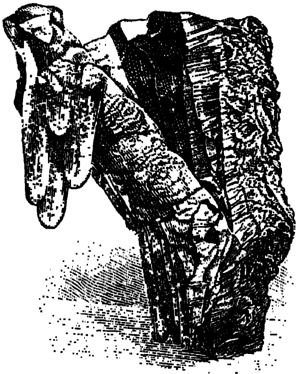

Fig. 364.
Stalactitic Structure.—Limonite.

Stalactitic.—When the material occurs in pendants (icicle-like forms), as limonite (Fig. 364) and some calcite (cave-stone). Stalactites form in cavities. The material is deposited generally from dripping water.

COHESION RELATIONS OF MINERALS.

Cleavage.—Crystallized substances usually exhibit a tendency to break more readily in some directions than in others, often yielding smooth surfaces which resemble crystal faces. This property is known as *cleavage.* The directions of cleavage are always parallel to possible crystal faces, and usually to faces with simple indices. Cleavage is a separation parallel to the molecular planes composing the crystal (Fig. 51, p. 157), and is due to the fact that the forces which unite the molecules are weaker in certain directions than in others. Some substances, such as calcite, gypsum, and mica, can be cleaved with great ease. Such cleavage is designated as *perfect*, and if the cleavage-fragment is held in an appropriate position, close to the eye, a *perfect reflection* of distant objects will be obtained from its surface. In some minerals cleavage is *poor*, or can only be detected with difficulty. In studying minerals the *ease* with which cleavage can be produced and its *direction*, or its relation to the crystal form, should be carefully noted. Often the cracks in a crystal reveal both the presence and the direction of cleavage. To produce a cleavage, place the edge of a knife-blade or chisel on a crystal face, parallel to the direction in which the cleavage is supposed to exist, and strike a sharp, quick blow with a hammer.

In the isometric system cleavage may be *cubic* (Fig. 95, p. 170, and Fig. 365), as in galena and halite; *octahedral* (Fig. 96, p. 170), as in fluorite; or *dodecahedral* (Fig. 97, p. 170), as in sphalerite.

In the hexagonal system cleavage is designated as *basal* or *prismatic* when parallel, respectively, to the faces lettered *c* or *m* (Fig. 194, p. 187). In the rhombohedral group it is often *rhombohedral* (Fig. 219, p. 193, and Fig. 366), as in calcite. This is characterized by being equal in three directions, but not at right angles to one another.

In the remaining systems cleavage is called *basal* when it is in *one* direction, parallel to the terminal face *c* (001) in the figures pp. 179 to 217, illustrated by apophyllite in the tetragonal, topaz in the orthorhombic, and orthoclase in the monoclinic systems. Cleavage is called *pinacoidal* when it is in *one* direction, parallel to the vertical pinacoids of the orthorhombic, monoclinic, or triclinic systems, as in stibnite (Fig. 283, p. 203) and gypsum (Fig. 322, p. 211), where it is parallel to the faces *b* (010). In orthoclase (Fig. 326, p. 211) there is a perfect *basal* cleavage parallel to *c* (001), and a less perfect cleavage at right angles to it, parallel to the *clinopinacoid* *b* (010). A cleavage is designated as *prismatic* when produced with equal ease in two directions, parallel to the faces *m* (110) or *a* (100) of the tetragonal system (pp. 179 to 183), or parallel to the faces *m* (110) in the orthorhombic and monoclinic systems (pp. 200 to 213). Amphibole furnishes a good example of prismatic cleavage.

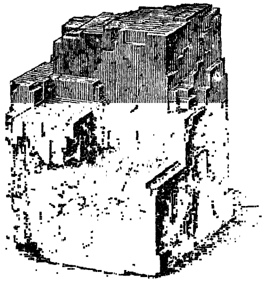

FIG. 365.
Cubic Cleavage.—Galena.

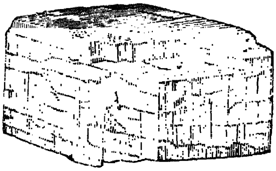

FIG. 366.
Rhombohedral Cleavage.—Calcite.

Parting.—It is the case in some crystals that when they are subjected to strain or pressure there is apparently a *slipping* or *gliding* of the particles along certain molecular planes. This is accompanied at times by an overturning of layers of molecules into the position which they would occupy in a twin crystal. By this process a weakness along these planes is developed, and the crystal may *part* or break with smooth surfaces. This phenomenon is called *parting* and is distinct, though not always readily distinguished, from cleavage, from which it differs in that it takes place *only where the molecular structure has been disturbed* by pressure or other agency, while cleavage in a given direction can be produced as readily in one part of a crystal as another.

Magnetite shows no perceptible cleavage, but specimens from certain localities show a perfect *octahedral parting* (Fig. 367).

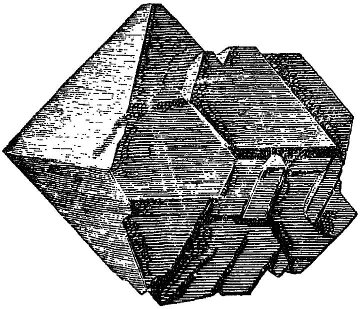

Fig. 367.
Octahedral Parting.—Magnetite.

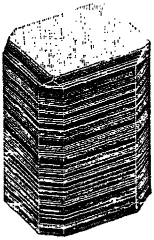

Fig. 368.
Twin Lamellæ and Basal Parting.—Pyroxene.

Pyroxene has a rather poor prismatic cleavage, but some crystals show twin lamellæ very distinctly and *parting* parallel to the basal plane (Fig. 368).

Fracture.—If a mineral has a poor cleavage, and separates or breaks almost as readily in one direction as in another, smooth, curved surfaces often result (Fig. 369). This kind of fracture is called *conchoidal*, from its resemblance to the curved surface of a shell. It is especially characteristic of amorphous substances, such as glass, and of minerals having a poor cleavage, such as quartz, while it may occasionally be observed on minerals which cleave readily, as calcite.

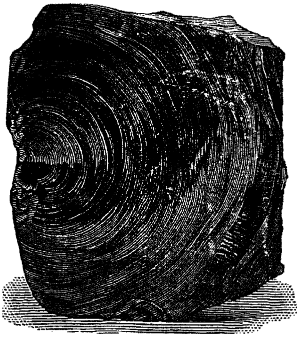

Fig. 369.
Conchoidal Fracture.—Obsidian or Volcanic Glass.

Fracture is said to be *uneven* when rough, irregular surfaces are obtained; *hackly* when a jagged, irregular surface like that of broken metal results; and *splintery* when the substance breaks in splinters or needles.

Tenacity.—A mineral is said to be *malleable* when it can be beaten out into plates by hammering; *sectile* when it can be cut with a knife, so that a shaving results; *flexible* when it bends readily, but does not resume its shape when the pressure is relieved; *elastic* when it bends and springs back to its original position.

Hardness.—The hardness of a mineral, or the resistance which it offers to being scratched, is expressed in terms of a *scale of hardness*, consisting of crystallized varieties of the following ten minerals:

Scale of Hardness.

1. Talc.
2. Gypsum.
3. Calcite.
4. Fluorite.
5. Apatite.
6. Orthoclase.
7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond.

The hardness of a mineral is determined by drawing a point, or a sharp corner of it across smooth surfaces of the different minerals in the scale of hardness until one is found which it will *just scratch*, while it will not scratch the next higher member in the scale. Thus if a mineral will scratch calcite but not fluorite its hardness will be between 3 and 4.

It is generally a simple matter to determine the hardness of a mineral, but there are some cases where considerable care and judgment must be exercised. For example, a soft mineral may crumble when drawn across a harder one, especially when the surface of the latter is rough, and leave a *mark*, similar to that of chalk on a blackboard, which readily rubs off and must not be mistaken for a scratch. Again, it is difficult to obtain the correct hardness of minerals which crumble readily or crystallize in fine needles or scales, for when drawn across the surfaces of the minerals in the scale of hardness they break down and do not offer sufficient resistance to make a distinct scratch on materials which may be considerably softer.

In determining the hardness of minerals a knife-blade will be found very useful. It will scratch apatite with some difficulty, but not orthoclase, and its hardness, therefore, is a little over 5.

With a little experience an approximation to the hardness of the softer varieties of minerals may be obtained by noting the *ease* with which they are scratched with a knife. The hardness of window-glass is about 5½, and some pieces of it will be found very useful. An ordinary brass pin will scratch calcite but not fluorite, and its hardness is, therefore, a little over 3. The finger-nail will scratch talc easily and gypsum with some difficulty.

Crystals exhibit varying degrees of hardness in different directions, being softer parallel to a cleavage direction than at right angles to it. This difference, however, is usually not sufficiently great to be detected by the ordinary methods of testing hardness. Cyanite furnishes a striking example, for in the direction of cleavage (parallel to the longer axis of the splinters) it can be readily scratched with a knife, while at right angles to the cleavage the hardness is considerably greater than that of steel.

PROPERTIES DEPENDING UPON LIGHT.*

Luster.—The luster of minerals, or their appearance due to the reflection, absorption, or refraction of light, furnishes an important means of identification, and is described by the following terms:

Metallic.—Having the luster and appearance of a metal, like lead or copper. Under this head those minerals are included which are *opaque*, that is, those which are not *at all transparent* when their thin edges are examined in a strong light. The powder of an opaque substance is *black* or *very dark*, because the small particles constituting it do not transmit any light; therefore this property may be usefully employed in detecting metallic luster. Pyrite and galena are examples of minerals with metallic luster.

Sub-metallic.—Dark-colored minerals which lack the true luster of a metal are called sub-metallic. Such substances are generally slightly transparent in *very thin splinters* and give *dark powders*, although the colors are considerably lighter than those of the compact minerals. Chromite, limonite, and some of the dark varieties of sphalerite are examples of minerals with sub-metallic luster.

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* Though fully appreciating the importance of the application of polarized light in the study of crystals and the identification of minerals, it has seemed best not to include these methods in the present work. For a description of them the student is referred to Idding's translation of Rosenbusch's *Mikroskopische Physiographie der petrographisch wichtigen Mineralien* or to Dana's *Text-book of Mineralogy.*

Non-metallic.—Transparent minerals are here included. If colorless, white, or light-colored they will give *white* powders, and if of decided colors their powders will be of lighter shades than those of the compact minerals. For example, a dark-green epidote yields a very pale green powder.

Transparent minerals exhibit the following kinds of luster: *Vitreous*, like the luster of glass. *Adamantine*, like the luster of a diamond. Minerals possessing this luster have a certain *brilliancy*, due to the strong refraction of light, i. e., they have a high index of refraction. Adamantine luster may be observed on some of the hard minerals used as gems and on cerussite and other transparent salts of lead. *Resinous*, or having the appearance of resin, as shown by transparent varieties of sphalerite. *Greasy* or *oily*, as if the mineral had a thin coating of oil over it, as shown by some specimens of serpentine and massive quartz. *Pearly*, like the luster of mother-of-pearl. This is due to the interference of light in minute cracks (Newton's rings). It may usually be observed on crystal faces parallel to which there is a perfect cleavage, as on the basal planes of an apophyllite crystal. *Silky*, like a skein of silk. This may be observed on minerals which have a fine fibrous structure.

Streak.—The streak of a mineral is the *color of its powder*. Provided the material is not too hard, this may be quickly determined by rubbing it on a piece of white, unglazed porcelain, and noting the color of the powder, or mark, which is left. Pieces of unglazed porcelain, called *streak-plates*, are made especially for this purpose.

Color.—The color of minerals is a property which should be carefully considered. A mineral with metallic luster will always show the same tone of color provided *fresh, unaltered material* or a *freshly broken surface* is examined. Thus, the color of chalcocite is steel-gray and of bornite brownish-bronze. On exposure to the air and light, however, the surfaces of minerals with metallic luster may become dull or tarnished and present quite a different appearance from that of the fresh material. For example, chalcocite becomes black, and a fresh surface of bornite tarnishes to a purplish tint in less than a day. A mineral without metallic luster has always a definite color provided it contains a constituent, like copper, iron, or chromium, which has the property of coloring its compounds. Thus, copper minerals are generally green or blue, those containing iron and chromium generally green, though of different shades, while chromates are red or yellow. Often, however, the color of a mineral with non-metallic luster is *variable*, as illustrated by fluorite, which is colorless, yellow, pink, green, and violet, or by tourmaline, which ranges from colorless, or white, through varying shades of pink, green, blue, and brown, to black. The causes for the variation in color of some minerals cannot be detected, since it takes such minute quantities of certain materials to impart color to minerals. In a few cases the color disappears upon the application of heat, and is supposed to be of the nature of an organic pigment. In the majority of cases, however, variation in color is due to the admixture of some isomorphous constituent which has the property of absorbing light. For example, the diopside variety of pyroxene, $CaMg(SiO_3)_2$, is colorless, but pyroxenes containing the isomorphous iron molecule $CaFe(SiO_3)$ vary from light to dark green, depending upon the amount of iron which they contain. As explained on p. 7, the variations in the color of sphalerite, from colorless, or nearly so, when pure ZnS, through brown to black, depend upon the amount of the isomorphous iron sulphide molecule FeS which the mineral contains.

Frequently a mineral is colored by some foreign constituent with which it is mechanically mixed. Thus jasper is quartz colored red or brown by an admixture of either hematite or limonite.

PROPERTIES DEPENDING UPON HEAT.

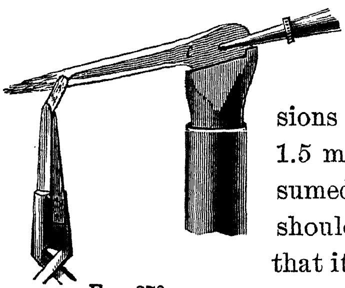

FIG. 370.
Method of holding a fragment of *Standard Size* when testing for the degree of fusibility.

Fusibility.—The ease with which substances fuse, or their *degree of fusibility*, admits of approximate determination, and is of great assistance in the identification of minerals. In testing fusibility, splinters of nearly uniform dimensions should be employed, and pieces about 1.5 mm. in diameter (Fig. 370) may be assumed as the *standard size.* The splinter should be held in the platinum forceps so that its end projects beyond the metal, then heated as shown in the figure. Provided its edges do not become rounded, a much finer splinter or a fragment with a very thin edge should be tested before deciding that the material is infusible. The fusibility of a mineral is determined by comparing its fusibility with that of a fragment of the *standard size* from the following scale:

*Scale of Fusibility.**

1. *Stibnite,* Sb_2S_3.	A rather large fragment fuses easily in a luminous lamp or gas flame. Fusible in a closed glass tube below a red heat.
2. *Chalcopyrite,* $CuFeS_2$.	A fragment of the standard size fuses rather slowly in a luminous lamp or gas flame. A small fragment fuses in a closed glass tube at a full red heat.
3. *Almandine Garnet,* $Fe_3Al_2(SiO_4)_3$.	A fragment of the standard size fuses readily to a globule before the blowpipe. In a luminous lamp or gas flame only the very finest splinters or thinnest edges are rounded.

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* With the exception of chalcopyrite the scale here adopted is that of Von Kobell, who made use of natrolite as No. 2. Natrolite, however, seems poorly chosen, for the range between stibnite and natrolite is considerable, while between natrolite and garnet the difference is slight.

4. *Actinolite*, $Ca(Mg,Fe)_3(SiO_3)_4$.	The edges of a fragment of the standard size are readily rounded before the blowpipe. A much finer splinter is easily fused to a globule.
5. *Orthoclase*, $KAlSi_3O_8$.	The edges of a fragment of the standard size are rounded with difficulty before the blowpipe. It is only when very fine splinters are employed that the material can be fused to a globule.
6. *Bronzite*, $(Mg,Fe)SiO_3$.	Only the finest points and thinnest edges become rounded before the blowpipe.

Glowing.—Some minerals *glow*, or emit a bright light, when heated intensely before the blowpipe. This is a property of *infusible* substances, and the oxides of calcium, magnesium, zirconium, and thorium possess it in a marked degree. Fragments of calcite $CaCO_3$, brucite $Mg(OH)_2$, and zircon $ZrSiO_4$, glow when intensely ignited. The Auer von Welsbach light is obtained by heating a *mantle* of thorium oxide with a Bunsen-burner flame.

Phosphorescence.—Some minerals when gently heated become luminous and emit light for a longer or shorter period. This property, known as *phosphorescence*, may be tested by heating fragments of a mineral in a closed tube, and best in a dark room. Many varieties of fluorite phosphoresce beautifully, with purple or green light. Some minerals phosphoresce when they are struck or rubbed; others after they have been exposed to sunlight or to an electric discharge.

Pyroelectricity.—Some minerals when they undergo a change of temperature become *electric* and have the property of attracting light bodies. This property, known as *pyroelectricity*, is especially characteristic of *hemimorphic* substances, i. e., those which show an unlike development of crystal forms at opposite extremities of an axis of symmetry (p. 164). Two kinds of electricity are always developed, positive at one end and negative at the other.

To detect pyroelectricity a crystal, held in the platinum forceps, is heated gently (not much above 100° C.), and as it cools it is brought near some small bits of tissue-paper, which will be attracted. A cat's hair which has been rubbed between the fingers and become positively electrified is excellent for detecting pyroelectricity, for it will be attracted to that end of the crystal where negative electricity prevails, and repelled by the other. A hair for this purpose may be fastened to a cork by means of sealing-wax and kept in a vial. Another very beautiful method is tried with a mixture of about equal volumes of red oxide of lead and flowers of sulphur. The mixture is kept in a vial, over the mouth of which two or three thicknesses of fine bolting-cloth are tied, so that the powder may be sifted out slowly. When agitated, the red oxide of lead becomes positively, and the sulphur negatively electrified, so that when the mixture is dusted upon an electrified body the red oxide of lead will be attracted to that part where there is negative, and the sulphur to where there is positive electricity. Experiments in pyroelectricity may be made with the light-colored varieties of tourmaline or with crystals or fragments of calamine. Generally the experiment succeeds best when a rather small fragment is employed.

PROPERTIES DEPENDING UPON WEIGHT.

Specific Gravity.—The specific gravity of a substance is the ratio of *its weight to the weight of an equal volume of water.* For example, quartz has a specific gravity of 2.65, and is, therefore, two and sixty-five hundredths times *heavier than water.*

Specific gravity is a definite property of all minerals *which show no variation in chemical composition,* and, when carefully determined, can be used to great advantage as a means of identification. There are, however, several conditions which must be carefully considered.

1. It is of the utmost importance that the material should be *pure.* If it is not, there is little or no advantage to be gained by taking its specific gravity.

2. A pure, transparent fragment of a mineral will apparently have a somewhat higher specific gravity than a piece which is full

of cracks, as the cracks contain air which tends to make the mineral lighter. Air can generally be expelled from cracks by boiling the fragment in water for some minutes, when an accurate determination may be made.

3. It is difficult and often impracticable to obtain the correct specific gravity of porous, earthy, and fine fibrous, or scaly, minerals because of the air which they confine. Moreover, the chances of their containing impurities are also great and must be taken into consideration.

4. Minerals which show a variation in chemical composition may exhibit considerable range in specific gravity. This is especially true when there is an isomorphous mixture of two molecules with widely different molecular weights, as in the case of the niobate and tantalate of iron, explained on p. 7. In such cases, however, the specific gravity determinations may have great value, as furnishing a means of approximately determining the proportions of the isomorphous constituents.

In the tables for the determination of minerals, pains have been taken to give, as accurately as possible, the specific gravity of the *pure crystallized varieties* of each mineral. Variations from these figures should be small, provided the material that is tested is pure and its specific gravity is taken correctly.

The usual method for taking specific gravity is to weigh a substance in air and then when immersed in water. The *difference* in these values is the weight of a quantity of water *equal to the volume of the substance*, for a body when immersed in water is buoyed up by a weight equal to that of the water displaced. If Wa is the weight of a substance in air and Ww its weight when immersed in water, its specific gravity is found by dividing Wa by $Wa - Ww$.

For very accurate determinations the weights should be taken on a chemical balance. The material is first boiled in water for some minutes to expel the air, then allowed to cool in the water to the temperature of the room. It is then conveniently placed in a wire basket, suspended from the arm of a chemical balance by a very fine platinum wire (Fig. 371), and the weight in water determined, from which the weight of the empty basket in water should be deducted. The material is then weighed, after being thoroughly dried. For practical purposes corrections for temperature may be neglected, for they will be trifling if the weighings are made at the temperature of an ordinary living-room.

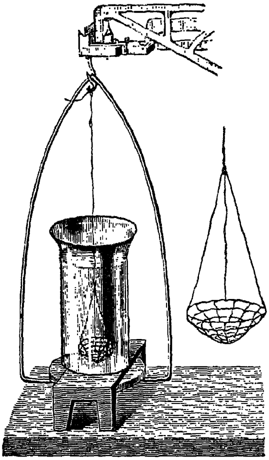

FIG. 371.
Method of hanging wire basket on balance beam for weighing substances in water. (Wire basket at the side.)

For quick results in the identification of minerals, the following simple methods will be found convenient and sufficiently reliable for all ordinary purposes.

The Spring or Jolly Balance.—With this apparatus (Fig. 372) the *relative weights* of a substance are determined by the *stretch* of a spiral spring. Two pans are carried at the lower end of the spring; the upper one *c* being in the air and the lower one *d* in water which is in a glass resting upon the sliding platform *B*. The stretch of the spring is read from a scale which is engraved upon a mirror fastened to the upright *A*. A white porcelain bead at *m* serves as a mark for noting the position of the spring with reference to the scale. It is evident that in order to make these readings correctly, the eye must be on the same level as the bead. This is accomplished by bringing the eye into a position where the top of the bead and its reflection in the mirror coincide. The pans being empty and the lower one *d* being suspended in the water near the bottom of the glass, the position of the bead *m* is noted on the scale, $= x$. A fragment of mineral, sufficient

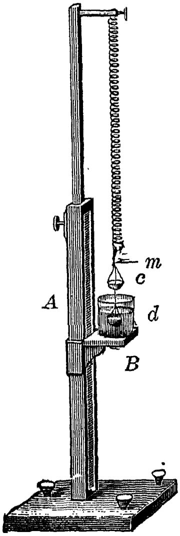

FIG. 372.
Spring or Jolly Balance for Specific Gravity.

to stretch the spring somewhat more than one half the length of the scale, is then placed in the upper pan and the platform lowered until the spring comes to rest, the pan d occupying the same relative position in the water as before, when the position of the bead is again noted, $= y$. Hence $y - x$ is the *weight in air.* The fragment is now transferred to the lower pan, and the platform raised until d occupies the same position in the water as before, when the position of the bead is again noted, $= z$. Hence $y - z$ is the *loss of weight in water*, and the weight in air divided by the loss of weight in water gives the specific gravity.

The Beam Balance.—This is a simple piece of apparatus (Fig. 373) which can be easily constructed. The beam of wood is supported on a fine wire, or needle, at b and must swing freely. The long arm bc is divided into inches and tenths, or into any decimal scale, commencing at the fulcrum b; the short arm carries a double arrangement of pans, so suspended that one of them is in the air and the other in water. A piece of lead on the short arm serves to almost balance the long arm, and, the pans being empty, the beam is brought to a horizontal position, marked on the upright, near c, by means of a rider d. A number of counterpoises are needed, which do not have to be of any specific denomination as it is their position on the beam and not their actual weight which is recorded. Most handy are bits of bent wire which may be used as shown at A. The beam being adjusted by means of the rider d, a fragment of mineral is placed in the upper pan and a counterpoise is chosen, which, when placed near the end of the long arm, will

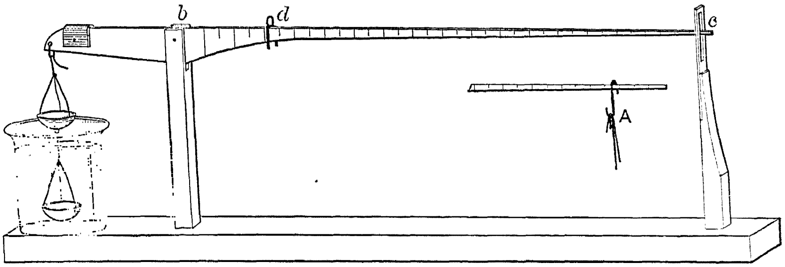

Fig. 373.
Beam Balance for Specific Gravity, $\frac{1}{6}$th Natural Size.

bring it into a horizontal position. The weight of the mineral in air, *Wa*, is given by the position of the counterpoise on the scale. The mineral is next transferred to the lower pan, and the *same counterpoise* is brought nearer the fulcrum *b* until the beam becomes again horizontal, when its position gives the weight of the mineral in water, *Ww*. *Wa* divided by *Wa* – *Ww* gives the specific gravity.

The balance has been repeatedly tested with pure materials, and the variation from determinations made on a chemical balance has never exceeded two in the second place of decimals. It is reliable, quick, and sufficiently accurate for all ordinary uses.

The Heavy Solution.—By treating 50 grams of mercuric iodide and 40 grams of potassium iodide in a porcelain dish, or casserole, with a little water, and evaporating until a crystalline crust begins to form, about 30 cubic centimeters of a yellowish-green solution are obtained, which has a specific gravity of about 3.15. This may be cleared by filtering, diluted with water to any extent, and the dilute solution may be brought to its maximum concentration by evaporation. It will keep indefinitely without decomposition, provided a few drops of mercury are added to it. It is very poisonous. In determining the specific gravity of a mineral by means of the heavy solution, a fragment is placed in it, and then, by adding water cautiously, the specific gravity of the solution is lowered until it becomes *exactly equal* to that of the mineral, when the fragment will remain suspended in any position, neither sinking nor floating. The specific gravity of the solution may then be taken by some of the methods described beyond.

The Westphal Balance.—This consists of a metal beam (Fig. 374) with its long arm from *l* to *h* divided into tenths. A glass sinker *r* loaded with mercury, is suspended from *h* by means of a fine platinum wire, and the apparatus is so constructed that, with the sinker in air, the beam-pointer can be brought to zero on the scale *s* by means of the set-screw *o*. Four wire riders *w* are needed, of such a weight that one of them, when hung at *h*, will bring the beam-pointer to zero when the sinker is immersed in water. There are also needed two lighter riders, one $\frac{1}{10}$ and the other $\frac{1}{100}$ of the *unit* weight. When the sinker *r* is immersed in the heavy solution the riders are applied, as illustrated in the figure, until the beam-pointer stands opposite zero. The two *unit*-riders at the end and one at 6 on the beam indicate a specific gravity of over 2.6. The $\frac{1}{10}$ and $\frac{1}{100}$ riders, both at 5, furnish the second and third figures from the decimal point and indicate that the specific gravity of the solution is 2.655.

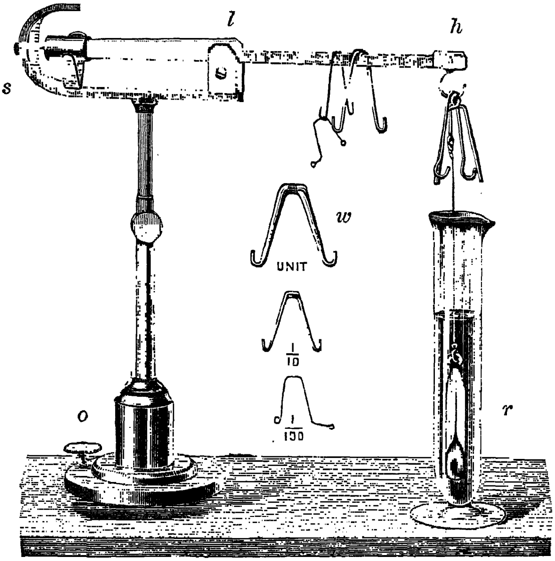

Fig. 374.
Westphal Balance for Taking the Specific Gravity of Liquids.

The *beam-balance* (Fig. 373) may also be employed. A sinker similar to *r* (Fig. 374) is suspended from a position marked by a notch near the end of the long arm. By putting shot in the pans and using the rider *d* the beam is brought to a horizontal position with the sinker *r* in air. The sinker is then immersed in the heavy solution and a weight is selected, which, when placed near the end of the beam, will bring the latter to a horizontal position. The position of this weight gives *relatively* the weight of the heavy solution displaced by the sinker. After washing, the sinker is immersed in water, and the *same weight* is placed nearer the fulcrum until the beam becomes horizontal. The position of this weight gives *relatively* the weight of the water displaced by the sinker. The larger weight divided by the smaller gives the desired specific gravity.

It may often be found convenient, in the identification of a gem, to use the heavy solution for comparing an unknown with a known mineral, as follows: A stone supposed to be beryl and a known crystal of beryl are placed together in the heavy solution, and water is added to determine whether they sink and float together, i. e., whether they are identical in specific gravity.

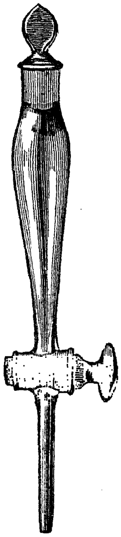

FIG. 375.
Separatory Funnel.
¼ Natural Size.

The heavy solution may also be used for obtaining a mineral in a state of purity when mixed with others of different specific gravity. The material is pulverized and sifted to a uniform grain, then introduced into the heavy solution. The specific gravity may then be adjusted, first so that everything heavier than the desired mineral will sink, and then so that everything lighter will float. The separation can be most readily accomplished in the apparatus shown in Fig. 375.

Besides the potassium mercuric iodide solution, which is the cheapest, and also the easiest to prepare and to manipulate, the following have proved very useful: methylen iodide,[*] CH_2I_2, with a maximum specific gravity of 3.32, and acetylen tetrabromide,[†] $CHBr_2$—$CHBr_2$, with a specific gravity of 3.01, both of which may be diluted with benzol; and barium mercuric iodide,[‡] with a maximum specific gravity of 3.55. The double salt, silver thallium nitrate,[§] melts at 75° C., giving a clear liquid with a maximum specific gravity of over 4.5, which may be diminished to any desired extent by adding hot water.

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[*] R. Branus, Jahrbuch für Mineralogie. 1886, Vol. II, p. 72.

[†] W. Muthman, Zeitschrift für Krystallographie, 1898, Vol. XXX, p. 73.

[‡] C. Rohrbach, Jahrbuch für Mineralogie, 1883, Vol. II, p. 186.

[§] J. W. Retgers, Jahrbuch für Mineralogie, 1893, Vol. I, p. 90; Author, Am. Jour. of Sci., 1895, Vol. L, p. 446.

CHAPTER VI.

TABLES FOR THE DETERMINATION OF MINERAL SPECIES BY MEANS OF SIMPLE CHEMICAL EXPERIMENTS IN THE WET AND DRY WAY AND BY THEIR PHYSICAL PROPERTIES.

INTRODUCTION TO THE TABLES.

In the GENERAL CLASSIFICATION of the tables (p. 245) minerals are divided into two groups: I, WITH METALLIC OR SUB-METALLIC LUSTER; II, WITHOUT METALLIC LUSTER. According to the explanations on pp. 227 and 228 this division depends upon the fact whether the minerals are *opaque* and give *black* or *dark* streaks, or *transparent* and give *white* or *light-colored* streaks. Since, whether the luster shall be considered metallic or non-metallic is, at times, wholly a matter of judgment, pains have been taken to place many minerals whose luster might be considered doubtful in both sections. A further subdivision of each group depends upon whether a mineral is fusible or infusible. The directions given on pp. 33 and 230 concerning fusion must here be carefully considered. In making the test, the degree of fusibility and perhaps some behavior, such as flame coloration, may be recorded, which will be of service in the identification of the mineral. Each section is then further subdivided, the divisions being based upon some chemical constituent which may be readily detected, or upon the behavior with acids.

In the tables p. 246 *et seq.*, the two vertical columns at the left give, respectively, the *General Characters* of groups of minerals and the *Specific Characters* of individual species, based, in most cases, upon simple blowpipe or chemical reactions. In the vertical columns headed *Species* the names of the minerals are given; and, since the tables are intended to include all of the minerals which are recognized as distinct species, this number is necessarily large, amounting to nearly 800 names. To facilitate the identification of a single species from this large number the names are printed in three ways. Those in CAPITALS indicate *common minerals*, that is, the ones which are found abundantly and are useful in the arts, or as ores of the metals, or are important geologically as constituents of rocks. Those in **Full-faced Type** indicate minerals which are valuable or important, but which do not occur often enough or in sufficient quantity to be considered as common. Names in small type indicate rare minerals. It will probably be found that usually out of one hundred specimens to be identified fully seventy-five will be the common minerals, printed in CAPITALS, with perhaps twenty **Intermediate** and five rare.

In the remaining columns the following important properties are recorded: Chemical Composition, pp. 3 to 9; Color, p. 228; Streak, p. 228; Luster, p. 227; Cleavage and Fracture, pp. 223 to 225; Hardness, p. 226; Specific Gravity, p. 232; Fusibility, p. 230; Crystallization, pp. 155 to 219.

METHOD OF USING THE TABLES.

The way in which the tables are used may be illustrated by the following examples:

Celestite.—Referring to the General Classification on p. 245 and examining the mineral, it will be seen that it is without metallic luster, and therefore belongs in Group II. A small fragment heated in the forceps before the blowpipe fuses rather readily, about 3.5 according to the scale of fusibility (p. 230), thus determining the mineral to be in Section B. It should be noted that a red coloration was imparted to the flame, indicating, according to the table of flame coloration on p. 136, probably either strontium or lithium. The mineral is not to be found in Parts I and II under B, because when its powder is fused with sodium carbonate on charcoal it does not yield a metallic globule, and when fused alone it does not yield a black, magnetic mass. It must, therefore, be in the remaining Part III. It may readily be proved to be in Division 1 under Part III, for when a fused fragment is placed on moistened turmeric-paper, it shows an alkaline reaction. Further, a test-tube trial will show that the mineral is insoluble in water, and hence is in section *b* on page 273. Referring to that page the first section under General Characters comprises *carbonates*, which dissolve in hydrochloric acid with effervescence. A test-tube trial of some of the powdered mineral under examination indicates that it is very insoluble in acids, and therefore not a carbonate. That the mineral belongs to the next section which comprises *sulphates* may readily be proved by fusing a little of it with sodium carbonate and charcoal-powder, and thus obtaining a mass which gives a dark stain when placed on moistened silver. The mineral, moreover, gives no water in the closed tube, and is difficultly soluble in boiling, dilute hydrochloric acid, as shown by a previous experiment made when testing for a carbonate. Under Specific Characters, the crimson flame coloration, tried best on platinum wire as directed on p. 35, determines the mineral to be *celestite*, strontium sulphate, $SrSO_4$. The physical properties given in the horizontal section should correspond: Color, *colorless or white;* Luster *vitreous;* Cleavage of two kinds, perfect in one direction, *basal*, and less perfect in two directions, *prismatic*, so that a form like Fig. 273, p. 201, may be produced; Hardness 3 to 3.5, the material scratches calcite and is readily scratched by fluorite; Specific gravity 3.97; Fusibility 3.5, which was determined at the outset; Crystallization, *orthorhombic*, crystals being perhaps like Figs. 278 or 279, p. 202. If the specific gravity had been taken at the beginning it would have served to distinguish celestite from all the other minerals in Division 1, *b*, pp. 273 and 274, for there are none which come at all close to 3.97.

Chromite.—The color of this mineral is black, and the powder, or streak, is dark brown; hence the luster may be considered as sub-metallic, and the mineral classified in Group I, p. 245. At the beginning, the hardness may be determined as between 5 and 6, and the specific gravity as 4.6. When heated before the blowpipe there is no indication of fusion; the mineral is therefore in Section B. Division 1, under B, includes minerals containing *iron*, which become magnetic after heating, but if a trial is made it will be found that the mineral does not become magnetic. In Division 2 the minerals containing *manganese* are included. A test made with borax in the oxidizing flame, as directed, gives a bead which is yellow when hot and yellowish green when cold. This does not indicate manganese, but is a decided reaction for chromium, as may be seen by referring to the table of reactions obtained with borax on p. 148. Since the mineral fails to give reactions for iron and manganese, it must belong in Division 3—Not belonging to the foregoing divisions, p. 256. Referring to this page in the column General Characters, the mineral cannot be in the first section because of its hardness. It is, however, in the second section, since the borax-bead test, previously made, has indicated the presence of *chromium*. This reaction, as well as the determinations of hardness and specific gravity, agree with *chromite*, $FeCr_2O_4 = FeO.Cr_2O_3$. A test for iron may be made with the magnet after fusion with sodium carbonate on charcoal, as directed under Specific Characters. Had the chromite been considered as being *without metallic luster*, Group II, p. 245, it would have been found under C, Division 5, *b*, p. 298.

Precautions in the Use of the Tables.—The system adopted in the construction of the tables is that of *eliminating* one group of minerals after another until a species is found, whose properties, as given in the table, correspond to the mineral that is being tested. The process of elimination and identification is based largely upon a series of chemical tests which, in almost all cases, give an insight into the character of the material. There is danger, however, that one may become so absorbed in following the tables mechanically, with the sole idea of determining the *name* of the species, as to wholly lose sight of the importance of making a careful study of the chemical reactions and physical properties of the minerals. It should be distinctly understood that little or nothing is to be gained by simply determining the name of a mineral. *The chief aim should be to obtain a thorough knowledge of the chemical composition, physical properties, and gen-*

eral appearances and associations of a mineral, not only that its uses and relations may be understood, but also that it may be easily recognized and identified when again encountered.

The general plan and arrangement of the tables must be adhered to rather closely, for if they are applied in the reverse direction, that is, *backwards*, they may not lead to the desired result. For example, if a mineral has metallic luster, is fusible, and gives a reaction for sulphur, it does not necessarily belong to Division 5 under I, A (p. 245), for most of the minerals containing *arsenic* (Division 1) and *antimony* (Division 4) also contain sulphur. It is, therefore, not correctly determined as belonging to Division 5 until proof has been obtained, not alone of the *presence of sulphur*, but also of the *absence* of arsenic and antimony, as well as of the rare elements selenicum and tellurium (Divisions 2 and 3).

The tables are adapted to the determination of *pure minerals.* If it is thought that a mineral is not pure the nature of the impurity must be taken into careful consideration. Thus, for example, many minerals are associated with calcite, $CaCO_3$. If some of this is included in material that is being tested it will cause a slight effervescence with acids and an alkaline reaction when the ignited material is applied to moistened turmeric-paper, although both reactions are probably entirely foreign to the mineral which it is desired to determine. The best and almost the only rule to guide one in such cases is one's *judgment.* It would be impossible to devise blowpipe methods to meet the contingencies arising from the various mixtures of minerals. The one thing of the *very utmost importance* is *the assurance of the purity and homogeneous character* of a mineral. Since, in most cases, only a very little material is required for the necessary tests, by careful selection enough can generally be secured in a pure condition.

RECORD OF MINERAL TESTS.

A careful record should be kept of all tests as they are made. It may be found convenient to record them, together with the physical properties, upon *blanks* similar to the accompanying sample. It is not intended that every test for which a space has been allotted should be made, but a convenient place has been furnished where the prominent blowpipe reactions may be recorded, provided tests in the closed or open tubes or with the fluxes, etc., have been made.

RECORD OF MINERAL TESTS. *

Structure ....

System of crystallization ....

Cleavage or fracture ....

Luster .... Color ....

Streak .... Hardness .... Sp. Gr. ....

Fusibility .... Flame color ....

Effect of acids and reactions with the solution ....

....

....

....

Closed tube ....

Open tube ....

Alone on charcoal ....

With fluxes on charcoal ....

With fluxes on platinum wire ....

Miscellaneous ....

....

....

NAME .... COMPOSITION ....

Per cent of chief constituents ....

Mode and place of occurrence ....

Associations ....

Uses ....

Number .... Date ....

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* Fifty of these blanks, bound in book form, may be obtained from the publishers. 50 cents, *net*.

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ANALYTICAL TABLE

SHOWING THE

GENERAL CLASSIFICATION

OF

MINERALS.

ABBREVIATIONS USED IN THE TEXT OF THE TABLES.

Amorph...	Amorphous.
Approx...	Approximately.
B. B......	Before the blowpipe.
Botryoid..	Botryoidal.
C........	Cleavage.
Capill....	Capillary.
Cl.........	Class.
Colum.....	Columnar.
Cryst.....	Crystalline; in crystals.
Direc.....	Direction.
F........	Fracture.
Fig.......	Figure.
Fol........	Foliated.
Fus.......	Fusibility.
Gran.....	Granular.
H........	Hardness.
HCl.......	Hydrochloric acid.
HNO_3....	Nitric acid.
H_2SO_4.....	Sulphuric acid.
Hemimor.	Hemimorphic.
Hexag....	Hexagonal.
Hex. Rh..	Hexagonal Rhombohedral.
Incrust....	Incrusting; incrustation.
Isom.....	Isometric.
Isom. Pyr.	Isometric Pyritohedral.
Isom. Tet.	Isometric Tetrahedral.
iso. w....	Isomorphous with.
Mamm....	Mammillary.
Mammill..	Mammillary.
Mass......	Massive.
Monocl...	Monoclinic.
Na_2CO_3...	Sodium carbonate.
Oct......	Octahedral.
O. F......	Oxidizing flame.
Orthorh..	Orthorhombic.
per.......	Perfect; referring to cleavage.
Pinac....	Pinacoidal; in one direction.
Prism....	Prismatic.
Pseudom..	Pseudomorphous.
Pyram....	Pyramidal.
Radiat....	Radiated.
R.F......	Reducing flame.
Sp. Gr....	Specific Gravity.
Sph.......	Sphenoidal.
Tabul....	Tabular.
Tar......	Tarnish.
Tetrag....	Tetragonal.
Tet. Sph..	Tetragonal Sphenoidal.
U........	Usually.
Vol......	Volatile.

N.B.—The chemical symbols of the elements, together with the valences which they ordinarily exhibit in mineral combinations and their atomic weights, will be found in Chapter III. "Reactions of the Elements," pp. 41 to 134.

GENERAL CLASSIFICATION.

☞ ***Success in using the following tables depends wholly upon locating a mineral with certainty in the group to which it belongs; hence it is evident that the initial reactions, as given in this GENERAL CLASSIFICATION, should be tried with the utmost care.***

☞ ***In testing the solubility of minerals the importance of using very fine powder, ground in an agate mortar, can not be overestimated.***

I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

NOTE.—Minerals having metallic luster are *opaque;* hence the color of their powder, or their *streak*, is dark, though not necessarily black (p. 227). The minerals with sub-metallic luster which are included in this section all give dark-colored streaks. Many dark-colored minerals whose luster is doubtful have been placed here, and also in Section II.

A.—FUSIBLE FROM 1—5, OR EASILY VOLATILE.

PAGE

1. Roasted in the open tube, or B. B. on charcoal, give a volatile sublimate of ***Arsenious Oxide*** (p. 48). Compare Antimony, Section 4........ 246
2. Roasted in the open tube, or B. B. on charcoal, give the characteristic radish-like odor of ***Selenium***. Impart an azure-blue color to the reducing flame (p. 107)........ 247
3. Treated in a dry test-tube with 3 cc. of concentrated H_2SO_4 and gently heated, the acid assumes a reddish-violet color characteristic for ***Tellurium*** (p. 124)........ 248
4. Roasted in the open tube, or B. B. on charcoal, give a dense white sublimate of ***Oxide of Antimony*** (p. 44). The sublimate is less volatile than that of arsenic........ 249
5. Roasted in the open tube, or B. B. on charcoal, give the odor of ***Sulphurous Anhydride*** (p. 118), but do not give the reactions of the preceding divisions........ 251
6. Not belonging to the foregoing divisions........ 253

B.—INFUSIBLE, OR FUSIBLE ABOVE 5, AND NON-VOLATILE.

1. Become magnetic after heating B. B. in the reducing flame, ***Iron*** (p. 84)........ 255
2. A minute quantity of material imparts to the borax bead in O. F. a reddish-violet color, ***Manganese*** (p. 93)........ 256
3. Not belonging to the foregoing divisions........ 256

II. MINERALS WITHOUT METALLIC LUSTER.

NOTE.—Minerals without metallic luster are *transparent*, although they may have such a dark color that they transmit light only through very thin edges. The color of their powder, or their *streak*, is generally white or light-colored, *never black* (p. 228).

A.—EASILY VOLATILE, OR COMBUSTIBLE.

1. Rapidly disappear when heated B. B. on charcoal. Only a few minerals behave thus.. 258

B.—FUSIBLE FROM 1—5, AND NON-VOLATILE, OR ONLY SLOWLY OR PARTIALLY VOLATILE.

Part I.—Give a METALLIC GLOBULE on charcoal.

1. Fused B. B. on charcoal with sodium carbonate give a globule of ***Silver*** (p. 113)........ 259
2. Fused B. B. on charcoal with sodium carbonate and charcoal dust give a globule of ***Lead*** and a coating of ***Lead Oxide*** (p. 87)........ 259
3. Fused B. B. on charcoal with sodium carbonate and charcoal dust give a globule of ***Bismuth*** and a coating of ***Bismuth Oxide*** (p. 54)........ 262
4. Fused B. B. on charcoal with sodium carbonate and charcoal dust give a globule of ***Antimony*** and a coating of ***Antimony Oxide*** (p. 44)........ 263
5. Fused B. B. on charcoal with a mixture of equal parts of sodium carbonate and borax give a globule of ***Copper*** (p. 73). The powdered mineral on charcoal, after moistening with hydrochloric acid, imparts an azure-blue color to the blowpipe flame........ 263

Part II.—Become Magnetic after Heating before the blowpipe in the reducing flame, Iron.

1. Soluble in hydrochloric or nitric acid without perceptible residue, and without yielding gelatinous silica upon evaporation. Mostly ***Sulphates, Arsenates and Phosphates.*** 266
2. Soluble in hydrochloric or nitric acid and yield gelatinous silica on evaporation, or are decomposed with the separation of silica, ***Silicates***........ 269
3. Insoluble in hydrochloric acid........ 270

Part III.—Do NOT give a metallic globule, and do NOT become magnetic.

1. Give an alkaline reaction on moistened turmeric-paper *after intense ignition before the blowpipe*, held either in the forceps or, if very easily fusible, in a loop on platinum wire. ***Salts of the Alkali and Alkali-earth Metals.***
   - *a*) Easily and completely soluble in water........ 271
   - *b*) Insoluble in water, or difficultly or only partly soluble........ 273
2. Soluble in hydrochloric acid, but do not yield a jelly or a residue of silica on evaporation. Mostly ***Arsenates, Phosphates and Borates***........ 275
3. Soluble in hydrochloric acid and yield gelatinous silica on evaporation. ***Soluble Silicates.***
   - *a*) In the closed tube give water........ 278
   - *b*) In the closed tube give little or no water........ 279
4. Decomposed by hydrochloric acid with the separation of silica, but without going wholly into solution and without giving a jelly on evaporation. ***Decomposable Silicates.***
   - *a*) In the closed tube give water........ 281
   - *b*) In the closed tube give little or no water........ 283
5. Insoluble in hydrochloric acid. Mostly ***Insoluble Silicates***........ 283

C.—INFUSIBLE, OR FUSIBLE ABOVE 5.

1. Give an alkaline reaction on moistened turmeric-paper *after intense ignition before the blowpipe*. ***Salts of the Alkali-earth Metals***........ 289
2. Soluble in hydrochloric acid, but do not yield a jelly or a residue of silica on evaporation. Mostly ***Carbonates, Sulphates, Oxides, Hydroxides and Phosphates***........ 290
3. Soluble in hydrochloric acid and yield gelatinous silica on evaporation. ***Soluble Silicates.*** 294
4. Decomposed by hydrochloric acid with the separation of silica, but without going wholly into solution and without giving a jelly on evaporation. ***Decomposable Silicates***........ 295
5. Insoluble in hydrochloric acid.
   - *a*) Hardness less than that of glass or steel. Can be scratched by a knife........ 296
   - *b*) Hardness equal to or greater than that of glass. Can not be scratched by a knife. 298

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I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1-5, or Easily Volatile.

DIVISION 1.—**Arsenic Compounds**, in part.

A.—Fusible from 1–5, or Easily Volatile.

Division 1.—**Arsenic Compounds.**—When heated before the blowpipe on charcoal, a white coating of arsenious oxide deposits at a considerable distance from the assay, and a garlic-like odor of arsenic is often obtained, p. 48. Of other reactions for arsenic, roasting in the open tube is especially recommended, and, in some cases, heating in the closed tube gives decisive results.

N. B.—The minerals in this division are chiefly the *arsenides* and *sulpharsenites of the metals*, p. 47.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
B. B. volatile without fusion.	In the closed tube gives a sublimate of arsenic.	**Arsenic.**	As.	Tin-white. Tar. dark gray.	Gray.	C. Basal, *per.*	3.5	5.7	Vol.	Hex. Rh. U. gran.
B. B. on charcoal fuses, and gives a white coating of oxide of antimony.	In the closed tube gives a sublimate of arsenic, leaving a fused globule of antimony.	Allemontite.	As with Sb.	Tin-white. Tar. gray.	Gray.	C. Basal, *per.*	3.5	6.20	1	Hex. Rh. U. gran.
Contain *lead.*—With Na_2CO_3 on charcoal give globules of lead and a coating of lead oxide. Oxidized by concentrated HNO_3 with the separation of lead sulphate.	Distinguished by crystallization and specific gravity. Sartorite decrepitates strongly.	Sartorite.	$PbS.As_2S_3$.	Lead-gray.	Dark brown to black.	C. Basal, F. Conchoidal.	3	5.40	1	Orthorh.
		Dufrenoysite.	$2PbS.As_2S_3$.	Blackish-gray.	Dark-brown to black.	C. Basal, *per.*	3	5.56	1	Monocl.
		Guitermanite.	$3PbS.As_2S_3$?	Bluish-gray.	Black.	F. Uneven.	3	5.9	1	Massive.
		Jordanite.	$4PbS.As_2S_3$.	Blackish-gray.	Black.	C. Pinacoidal. F. Uneven.	3	6.40	1	Monocl.
Contains *silver.*—With Na_2CO_3 on charcoal in O. F., gives a globule of silver.	The dilute HNO_3 solution assumes a blue color when treated with ammonia in excess (*copper*).	**Pearceite.** See *polybasite*, p. 250.	$9(Ag,Cu)_2S.As_2S_5$. Sb iso. w. As.	Black.	Black.	F. Conchoidal.	3	6.15	1	Monocl.
Contain *copper* and *sulphur.*—Roasted on charcoal, then moistened with HCl and again ignited, give a blue or green flame. The HNO_3 solution is rendered blue by addition of ammonia in excess. When roasted in an open tube the odor of sulphur dioxide is evolved.	In the HNO_3 solution, ammonia produces a rather abundant precipitate of *ferric hydroxide.*	Epigenite.	$4Cu_2S.3FeS.As_2S_5$?	Steel-gray.	Black.	F. Uneven.	3.5		2?	Orthorh.
	Contain little or no iron. Distinguished by physical properties. Enargite is easily cleavable, the others are not.	**Enargite.**	$3Cu_2S.As_2S_5$.	Grayish-black	Gray-black.	C. Prism., *per.* F. Uneven.	3	4.44	1	Orthorh. U. cryst.
		Tennantite. See *tetrahedrite*, p. 250.	$4Cu_2S.As_2S_3$. Ag_2,Zn, and Fe iso. w. Cu_2; Sb iso. w. As.	Blackish-gray.	Black to deep cherry-red.	F. Uneven.	3–4	4.6	1.5	Isom. Tet. Cryst. & Mass.
		Binnite.	$3Cu_2S.2As_2S_3$.	Iron-black.	Black.	F. Conchoidal.	2.5–3	4.47	1.5?	Isometric.
		Lautite.	CuAsS.	Iron-black.	Black.	C. not distinct.	3	4.9	1.5?	Prismatic.
Contain *copper*, reactions as above, but no *sulphur.*	Distinguished by physical properties. All exhibit a brownish tarnish on exposed surfaces.	Domeykite.	Cu_3As.	Steel-gray.	Gray.	F. Uneven.	3–3.5	7.5	2	Massive.
		Algodonite.	Cu_6As.	Steel-gray.	Gray.	F. Uneven.	4	7.6	2	Massive.
		Whitneyite.	Cu_9As.	Silver-white.	Silver-white.	Malleable. F. Hackly.	3.5	8.5	2	Massive.
Contain *cobalt.* — Give to the borax bead a sapphire-blue color. The concentrated HNO_3 solution generally shows a delicate rose color, thus distinguishing the cobalt from the nickel minerals on the next page.	With potassium iodide and sulphur, on charcoal, give the reaction for *bismuth*, p. 55, § 2. Distinguished by differences in crystallization.	Alloclasite.	Co(As,Bi)S. Fe. iso. w. Co.	Steel-gray.	Black.	C. Prism., *per.* F. Uneven.	4.5	6.6	2?	Orthorh. U. Colum.
		Bismutosmaltite.	$Co(As,Bi)_3$.	Tin-white.	Black.		6	6.92	2?	Isometric.
	Give a sublimate of arsenic in the closed tube, and contain little or no sulphur. ☞ Compare *Chloanthite*, p. 247, which often contains sufficient cobalt to give a blue color to the borax bead.	**Smaltite.**	$CoAs_2$. Fe and Ni iso. w. Co.	Tin-white.	Black.	C. Octahedral. F. Uneven.	5.5–6	6.3–6.5	2.5	Isom. Pyr.
		Safflorite.	$CoAs_2$. Fe iso. w. Co.	Tin-white. Tar. dark-gray	Black.	C. Pinacoidal. F. Uneven.	4.5–5	6.9–7.3	2.5	Orthorh.
		Skutterudite.	$CoAs_3$.	Tin-white to lead-gray.	Black.	F. Uneven.	6	6.75	2.5	Isom. Pyr.
	Give reactions for both *sulphur* and *arsenic* in the open tube. In the closed tube a sublimate of arsenic is not formed except upon intense ignition.	**Cobaltite.**	CoAsS. Fe iso. w. Co.	Tin-white, with reddish tone.	Black.	C. Cubic. F. Uneven.	5.5	6–6.2	2–3	Isom. Pyr
		Glaucodot.	(Co,Fe)AsS.	Grayish-white.	Black.	C. Basal. F. Uneven.	5	5.95	2–3	Orthorh.

Division 1.—**Arsenic Compounds.**—Concluded on next page.

(Page 247.)

1. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1-5, or Easily Volatile.

DIVISION 1.—**Arsenic Compounds,** concluded.

DIVISION 2.—**Selenium Compounds,** in part.

A.—Fusible from 1—5, or Easily Volatile.

Division 1.—**Arsenic Compounds.**—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain *nickel*.—Impart to the borax bead a reddish-brown color. Give apple-green-colored solutions when dissolved in HNO_3, which become blue when diluted and treated with ammonia in excess. (This reaction for nickel must not be confounded with the more intense blue which is produced when solutions containing copper are similarly treated.)	Give a sublimate of arsenic in the closed tube, and contain little or no sulphur.	**Chloanthite.**	$NiAs_2$. Fe and Co iso. w. Ni.	Tin-white.	Black.	C. Octahedral. F. Uneven.	5.5–6	6.4–6.8	2	Isom.Pyr.
		Rammelsbergite.	$NiAs_2$.	Tin-white, with reddish tinge.	Black.	C. Prismatic. F. Uneven.	5.5–6	6.9–7.2	2	Orthorh.
	On intense ignition in the closed tube gives a slight sublimate of arsenic. ☞ Compare *Breithauptite*, p. 250.	**Niccolite.** (Copper Nickel.)	$NiAs$. Sb and S iso. w. As.	Pale copper-red.	Brownish-black.	F. Uneven.	5–5.5	7.5	2	Hexag. U. mass.
	Gives reactions for both sulphur and arsenic in the open tube, but contains no antimony. In the closed tube a sublimate of arsenic is not formed except upon intense ignition.	**Gersdorfite.**	$NiAsS$. Fe and Co iso. w. Ni.	Tin-white.	Black.	C. Cubic. F. Uneven.	5.5	5.8–6.2	2	Isom.Pyr.
	Give reactions for sulphur, antimony, and arsenic in the open tube.	Corynite.	$Ni(As,Sb)S$.	Tin-white.	Black.	F. Uneven.	4.5–5	6.0	2	Isometric.
		Wolfachite.	$Ni(As,Sb)S$.	Steel-gray.	Black.	C. Prismatic. F. Uneven.	4.5	6.6	2	Orthorh. U. colum.
Contain *iron*. — B. B. fuse to strongly magnetic globules. The dilute HNO_3 solution, when treated with ammonia in excess, yields a reddish-brown precipitate of *basic ferric arsenate*.	Gives reactions for both arsenic and sulphur in the open tube. Gives an abundant sublimate of arsenic in the closed tube.	**ARSENOPYRITE.** (Mispickel.)	$FeAsS$. Occasionally Co iso. w. Fe.	Silver-white.	Black.	C. Prismatic. F. Uneven.	5.5–6	6–6.2	2	Orthorh. U. cryst. Page 203.
	Contains no, or only a trace of, sulphur. Massive varieties can be identified with certainty only by means of a quantitative chemical analysis.	Löllingite.	$FeAs_2$.	Silver-white.	Black.	C. Basal. F. Uneven.	5–5.5	7.2–7.3	2	Orthorh.
		Leucopyrite.	Fe_3As_4.	Silver-white.	Black.	F. Uneven.	5–5.5	6.9–7.1		Massive.
Contains *platinum*.—Roasted in the open tube, at first very gently, a platinum sponge is left, which is insoluble in any single acid. Fuses readily to a globule when heated rapidly on charcoal. Test for platinum as directed on p. 103.		Sperrylite.	$PtAs_2$.	Tin-white.	Black.	F. Conchoidal	6–7	10.60	2	Isom.Pyr.

Division 2.—**Selenium Compounds.**—When heated before the blowpipe on charcoal, the characteristic radish-like odor of selenium is obtained, and the reducing flame is tinged a beautiful azure-blue, p. 107.

N.B.—The minerals in this division are mostly the *selenides of the metals*. None of them are of common occurrence.

Contains *tellurium*. — B. B. wholly volatile.	In the open tube a sublimate of TeO_2 is formed, which fuses to colorless drops.	Selen-tellurium.	Te with Se.	Blackish-gray.	Black.	C. Prismatic, *perfect*.	2–2.5		1	Hexag. Massive.
Contain *mercury*.—Heated in the closed tube with Na_2CO_3, give metallic mercury (p. 94). Heated alone in the closed tube, give a metallic-gray sublimate of mercuric selenide. B. B. wholly volatile.	Fused with Na_2CO_3 on charcoal, gives globules of *lead* and a coating of *lead oxide*.	Lehrbachite.	$(Pb,Hg)Se$.	Lead-gray to iron-black.	Black.			7.85	1	Massive.
	Gives *sulphur dioxide* when heated in the open tube.	Onofrite.	$Hg(S,Se)$.	Blackish-gray.	Black.	F. Conchoidal.	2.5	8.0	Vol.	Massive.
	Contains no, or only a trace of, sulphur.	Tiemannite.	$HgSe$.	Blackish-gray.	Black.	F. Conchoidal.	2.5	8.2	Vol.	Isom.Tet. U. mass.
Contain *copper*.—Fuse B. B. to globules which, after moistening with HCl, color the flame azure-blue. The HNO_3 solution is rendered deep-blue by addition of ammonia in excess.	When heated alone, B. B. colors the flame green (*thallium*).	Crookesite.	$(Cu,Tl,Ag)_2Se$.	Lead-gray.	Black.	F. Uneven.	2.5–3	6.9	1	Massive.
	The HNO_3 solution gives with HCl a white precipitate of *silver chloride*.	Eucairite.	CuAg Se.	Lead-gray.	Shining.		2.5	7.5	2	Isometric. U. mass.
	The HNO_3 solution gives with H_2SO_4 a precipitate of *lead sulphate*.	Zorgite.	$(Pb,Cu_2)Se$.	Lead-gray.	Black.		2.5	7–7.5	1	Massive. U. gran.
	Contain only selenium and copper.	Berzelianite.	Cu_2Se. Ag iso. w. Cu.	Silver-white.	Shining.	F. Uneven.	2 ?	6.7	1.5	Massive.
		Umangite.	Cu_3Se_2.	Dark cherry-red.	Black.		3	5.62	1.5	Massive.

Division 2.—**Selenium Compounds.**—Concluded on next page.

(Page 248.)

I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1-5, or Easily Volatile.

DIVISION 2.—**Selenium Compounds,** concluded.

DIVISION 3.—**Tellurium Compounds.**

DIVISION 4.—**Antimony Compounds.**—When heated before the blowpipe on charcoal the dense white coating of oxide of antimony deposits near the assay (p. 44). The test for antimony with the open tube may also be recommended.

N. B.—Most of the minerals in this division are the *sulphantimonites of the metals.* The sulphur may be detected by roasting in the open tube.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Easily and completely volatile when heated B. B. on charcoal. Do not give reactions for lead.	In the open tube yields a white, slowly volatile, crystalline sublimate of Sb_2O_3 (p. 45).	**Antimony.**	Sb.	Tin-white.	Gray.	C. Basal, *per.*	3–3.5	6.6–6.7	1	Hex. Rh. U. gran.
	In the open tube yields SO_2 and for the most part a dense, white, non-volatile sublimate of Sb_2O_4 (p. 45).	**STIBNITE.** (Antimony Glance.)	Sb_2S_3	Lead-gray.	Gray-black.	C. Pinacoidal, *perfect.* F. Uneven.	2	4.55	1	Orthorh. Page 202.
	Reacts for mercury when heated in the closed tube with Na_2CO_3.	**Livingstonite.**	$HgS.2Sb_2S_3$.	Lead-gray.	Reddish.		2	4.81	1	? Prismatic.
Contain *lead.*—After carefully roasting on charcoal (p. 39) the residue, when scraped up with Na_2CO_3 and fused in R. F., gives globules of metallic lead. The iodine tests for lead (p. 89) are very decisive. When roasted alone on charcoal are nearly or completely volatile. Oxidized by concentrated nitric acid, with the separation of metantimonic acid (p. 46, § 6), lead sulphate, and usually of sulphur. ☞ Compare *Galena* (p. 251), which, when roasted alone on charcoal, sometimes gives a coating resembling that of antimony (p. 88).	Contains *copper.*—When decomposed by HNO_3 and treated with ammonia in excess, the solution assumes a deep blue color.	**Bournonite.**	$2PbS.Cu_2S.Sb_2S_3$.	Steel-gray.	Black.	F. Uneven.	2.5–3	5.80	1	Orthorh. U. cryst.
	Contains *bismuth.* — Fused on charcoal with potassium iodide and sulphur gives a red sublimate.	**Kobellite.**	$2PbS.(Bi,Sb)_2S_3$.	Blackish-gray.	Black.		2.5–3	6.30	1	Massive. Prismatic.
	Contain *silver.*—The HNO_3 solution, filtered if necessary, gives with HCl a precipitate of *silver chloride* which is insoluble in hot water (difference from lead chloride, p. 89, § 4). A globule of silver is obtained by continued heating on charcoal in O. F.	Andorite.	$2PbS.Ag_2S.3Sb_2S_3$.	Dark steel-gray.	Black.	F. Conchoidal.	3–3.5	5.33	1	Orthorh.
		Brongniardite.	$PbS.Ag_2S.Sb_2S_3$.	Grayish-black.	Black.	F. Uneven.	3–3.5	5.95	1	Massive.
		Diaphorite.	$5(Pb,Ag_2)S.2Sb_2S_3$.	Steel-gray.	Black.	F. Uneven.	2.5–3	5.9–6.0	1	Orthorh.
		Freieslebenite.	$5(Pb,Ag_2)S.2Sb_2S_3$.	Steel-gray.	Black.	F. Uneven.	2–2.5	6.2–6.4	1	Monocl.
	Contain *tin.*—When heated in O. F. on charcoal leave an infusible mass of oxide, which, when mixed with Na_2CO_3 and charcoal powder, and fused in R. F., gives a malleable metallic globule.	Cylindrite. (Kylindrite.)	$6PbS.6SnS_2.Sb_2S_3$.	Blackish-gray.	Black.	F. Uneven.	2.5–3	5.42	1.5	Rolls.
		Franckeite.	$5PbS.2SnS_2.Sb_2S_3$.	Blackish-gray.	Black.	C. Pinacoidal.	2.5–3	5.55	1	Tabular.
	Contain neither *copper, bismuth, tin,* nor *silver.*—The minerals are distinguished by differences in crystallization and physical properties.	Zinkenite.	$PbS.Sb_2S_3$.	Steel-gray.	Black.	F. Uneven.	3–3.5	5.35	1	Orthorh.
		Plagionite.	$5PbS.4Sb_2S_3$.	Blackish-gray.	Black.	F. Uneven.	2.5	5.40	1	Monocl.
		Warrenite.	$3PbS.2Sb_2S_3$.	Blackish-gray.	Black.				1	Capillary.
		Jamesonite. (Feather Ore.)	$2PbS.Sb_2S_3$.	Blackish-gray.	Black.	C. Basal, *per.* F. Uneven.	2–3	5.5–6.0	1	Orthorh. U. capill.
		Semseyite.	$7PbS.3Sb_2S_3$.	Gray.	Black.	C. Pyramidal.		5.95	1	Monocl. U. tabul.
		Boulangerite.	$3PbS.Sb_2S_3$.	Bluish lead-gray.	Black.	F. Smooth.	2.5–3	5.75–6.0	1	Gran. & Compact.
		Meneghinite.	$4PbS.Sb_2S_3$.	Blackish-gray.	Black.	C. Pinac., *per.*	2.5	6.35	1	Orthorh. U. prism.
		Geocrinite.	$5PbS.Sb_2S_3$.	Lead-gray.	Black.	C. Prismatic. F. Uneven.	2.5	6.40	1	Orthorh. U. mass.
		Kilbrickenite.	$6PbS.Sb_2S_3$?	Lead-gray.	Black.			6.40	1	Massive.
		Epiboulangerite.	$3PbS.Sb_2S_5$.	Blackish-gray.	Black.			6.31	1	Orthorh.? Prismatic.

DIVISION 4.—**Antimony Compounds.**—Continued on next page.

(Page 250.)

I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1-5, or Easily Volatile.

DIVISION 4.—**Antimony Compounds**, concluded.

A.—Fusible from 1–5, or Easily Volatile.

DIVISION 4.—Antimony Compounds.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain *silver*, but do not give the foregoing reactions for lead.—After decomposing with HNO_3 and filtering, the solution reacts for silver with HCl. When only the volatile elements, antimony and sulphur, are present with silver, a globule of the pure metal may be obtained by fusion and continued heating on charcoal in O. F. The coating of oxide of antimony in this case assumes a reddish to deep lilac tint (p. 114). Often, after the volatile constituents have to a large extent been driven away, the addition of a little Na_2CO_3, or borax, assists in the formation of the silver globule.	Contain *copper*.—When decomposed by HNO_3 and treated with ammonia in excess, a deep blue solution is obtained. ☞ Compare *Polybasite*, below.	Stylotypite.	$3(Cu_2,Ag_2,Fe)S.Sb_2S_3$.	Iron-black.	Black.	F. Uneven.	3	4.8	1–1.5	Orthorh.
		Freibergite. (Silver Tetrahedrite.)	$4(Cu,Ag)_2S.Sb_2S_3$. Fe and Zn iso. w. Cu_2.	Gray.	Black.	F. Uneven.	3–4	4.7–4.9	1.5	Isom. Tet. Page 175.
	Sulphantimonites of silver, containing no, or only traces of, copper. Give the odor of sulphur dioxide when roasted in the open tube. The crystals of Stephanite are usually stout, six-sided prisms. Those of Polybasite six-sided plates, with triangular markings on the basal planes.	Miargyrite.	$Ag_2S.Sb_2S_3$.	Iron-black.	Dark-red to black.	F. Uneven.	2–2.5	5.1–5.3	1	Monocl.
		Pyrargyrite. (Dark Ruby-silver.)	$3Ag_2S.Sb_2S_3$.	Deep-red to black.	Indian-red.	C. Rhomboh. F. Conchoidal.	2.5	5.85	1	Hex. Rh. Hemimor. Cl.13, p. 219.
		Stephanite.	$5Ag_2S.Sb_2S_3$.	Iron-black.	Black.	F. Uneven.	2–2.5	6.2–6.3	1	Orthorh.
		Polybasite. See *pearceite*, p. 246.	$9(Ag,Cu)_2S.Sb_2S_3$. As iso. w. Sb.	Iron-black.	Black.	F. Uneven.	2–3	6–6.2	1	Monocl.
		Polyargyrite.	$12Ag_2S.Sb_2S_3$.	Iron-black.	Black.	C. Cubic.	2.5	6.95	1	Isometric.
	Reacts only for antimony and silver.	Dyscrasite.	Ag_3Sb.	Silver-gray. Tar. black.	Gray.	C. Basal.	3.5–4	9.75	1.5	Orthorh.
Contain *copper*, but neither lead nor silver.—The dilute HNO_3 solution, filtered if necessary, gives a deep blue color with ammonia in excess.	Gives globules of mercury when heated in a closed tube with dry Na_2CO_3 (p. 94, § 1).	Schwatzite. (Mercurial Tetrahedrite.)	$4(Cu_2,Hg)S.Sb_2S_3$. Fe and Zn iso. w. Cu_2.	Dark-gray.	Black.	F. Uneven.	3–4	4.8–5.1	1.5	Isom. Tet. Page 175.
	Distinguished by differences in crystallization and physical properties.	Chalcostibite. (Wolfsbergite.)	$Cu_2S.Sb_2S_3$.	Blackish-gray.	Black.	C. Basal, *per.*	3–4	4.95–5.0	1	Orthorh.
		Falkenhaynite.	$3Cu_2S.Sb_2S_3$.	Grayish-black	Black.			4.83	1–1.5	Massive.
		TETRAHEDRITE. (Gray Copper.)	$4Cu_2S.Sb_2S_3$. Fe,Zn,Pb and Ag_2 iso. w. Cu_2; As iso. w. Sb.	Gray.	Black.	F. Uneven.	3–4	4.7–5.0	1.5	Isom. Tet. Page 175.
		Famatinite.	$3Cu_2S.Sb_2S_5$.	Gray, with reddish tone.	Black.	F. Uneven.	3.5	4.57	1–1.5	Orthorh.
Contains *iron*, but does not give the reactions of the foregoing divisions.	Fuses to a strongly magnetic globule.	Berthierite.	$FeS.Sb_2S_3$.	Steel-gray.	Black.	C. Longitudinal.	2–3	4–4.3	1.5–2	Prismatic. Fibrous.
Contains *nickel*. — The roasted mineral gives with borax in O. F. a brownish bead.	React for sulphur in the open tube. With potassium iodide and sulphur give the test for bismuth (p. 55, § 2).	Kallilite.	$Ni(Sb,Bi)S$.	Light bluish-gray.	Black.			7.01		Massive.
		Hauchecornite.	$Ni(Bi,Sb,S)$.	Bronze-yellow	Black.		5	6.4		Tetrag. U. mass.
	Reacts for sulphur, but contains no bismuth.	Ullmannite.	$NiSbS$.	Silver-gray.	Black.	C. Cubic, *per.*	5–5.5	6.5–6.7	1.5	Isometric. Cl. 5, p. 129
	Contains little or no sulphur. Some varieties react for arsenic.	Breithauptite.	$NiSb$. As iso. w. Sb.	Copper-red, violet tone.		F. Uneven.	5–5.5	7.54	1.5–2	Hexag.

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I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1-5, or Easily Volatile.

DIVISION 5.—Sulphides, in part.

I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1–5, or Easily Volatile.

Division 5.—**Sulphides.**—When roasted in the open tube *sulphur dioxide* (sulphurous anhydride) is formed, which may be recognized by its odor, and by the acid reaction which it imparts to a piece of moistened litmus-paper placed in the upper end of the tube. The reactions of the foregoing divisions should not be obtained.

N.B.—The minerals in this division are mostly sulphides of the metals. Sulphides containing arsenic, antimony, selenium, and tellurium will be found in the foregoing divisions. A few sulphides will be met with later on among the minerals without metallic luster.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain only *silver and sulphur*.—When fused alone on charcoal in O. F. a globule of pure silver is obtained.	Sectile, can be cut with a knife like lead.	**Argentite.**	Ag_2S.	Blackish-gray.	Blackish-gray.	F. Conchoidal.	2–2.5	7.3	1.5	Isometric.
		Acanthite.	Ag_2S.	Iron-black.	Black.	F. Uneven.	2–2.5	7.2–7.3	1.5	Orthorh.
Contain *bismuth*.—Mixed with potassium iodide and sulphur, and fused on charcoal in O. F. a red sublimate is obtained (p. 55, § 2). When lead is present, the yellow coating of lead iodide may obscure the foregoing reaction for bismuth. In order to make decisive tests for the two elements it is recommended to proceed as follows: Treat an ivory-spoonful of the powdered mineral in a test-tube with 3 cc. of HNO_3 and 1 cc. of concentrated H_2SO_4, and boil until the nitric acid is expelled. After cooling, add 5 cc. of water, boil for about a minute in order to dissolve the bismuth sulphate, and filter off the insoluble lead sulphate. This may be tested by fusing with Na_2CO_3 on charcoal. In the filtrate precipitate the bismuth as hydroxide with ammonia, filter, and test some of it by fusing on charcoal with the potassium iodide and sulphur mixture. If copper is present the ammoniacal filtrate from the bismuth will be blue.	Reacts only for sulphur and bismuth.	**Bismuthinite.** (Bismuth Glance.)	Bi_2S_3.	Lead-gray.	Gray.	C. Pinacoidal, *perfect*	2	6.4–6.5	1	Orthorh. Prismatic.
	Contain *lead* and *silver*.—Decompose with HNO_3, dilute with water, and filter. In the filtrate HCl will produce a precipitate of silver chloride which is insoluble in boiling water.	Schirmerite.	$3(Ag_2,Pb)S.2Bi_2S_3$.	Lead-gray.	Grayish-black.	F. Uneven.		6.75	1–1.5?	Massive.
		Schapbachite.	$PbS.Ag_2S.Bi_2S_3$.	Lead-gray.	Grayish-black.	C. Basal.	3.5	6.43	1–1.5?	Orthorh.?
	Contain *lead*, and not more than traces of silver.—Aikenite is characterized by containing copper, otherwise it may not be possible to identify the rare minerals in this group without a quantitative chemical analysis.	Chiviatite.	$2PbS.3Bi_2S_3$.	Lead-gray.	Grayish-black.	C. Distinct.		6.92	1–1.5?	Foliated.
		Rezbanyite.	$4PbS.5Bi_2S_3$.	Light lead-gray.	Grayish-black.	F. Uneven.	2.5–3	6.1–6.4	1–1.5?	Massive.
		Galenobismutite.	$PbS.Bi_2S_3$.	Lead-gray.	Grayish-black.		3–4	6.8–7.1	1–1.5?	Columnar
		Cosalite.	$2PbS.Bi_2S_3$. Ag_2, Cu_2 & Fe iso. w. Pb.	Lead-gray.	Grayish-black.	F. Uneven.	2.5–3	6.4–6.7	1–1.5	Orthorh. U. mass.
		Aikinite.	$3(Pb,Cu_2)S.Bi_2S_3$.	Blackish lead-gray.	Grayish-black.	F. Uneven.	2–2.5	6.7	1–1.5	Orthorh. Acicular.
		Lillianite.	$3PbS.Bi_2S_3$. Ag_2 iso. w. Pb; Sb iso. w. Bi.	Steel-gray.	Grayish-black.			6.1	1–1.5?	Massive.
		Beegerite.	$6PbS.Bi_2S_3$. Ag_2 iso. w. Pb.	Gray.	Grayish-black.	C. Cubic?		7.27	1–1.5?	Isometric?
	Contain *copper*.—When decomposed by nitric acid, the dilute solution is rendered blue by the addition of ammonia in excess.	Cuprobismutite.	$3Cu_2S.4Bi_2S_3$. Ag iso. w. Cu.	Bluish-black.	Black.			6.3–6.8	1	Slender prisms.
		Emplectite.	$Cu_2S.Bi_2S_3$.	Grayish-white.	Black.	C. Pinacoidal, *perfect.*	2	6.3–6.5	1	Orthorh.
		Klaprotholite.	$3Cu_2S.2Bi_2S_3$.	Steel-gray.	Black.	F. Uneven.	2.5	4.6?	1	Orthorh.
		Wittichenite.	$3Cu_2S.Bi_2S_3$.	Grayish-white.	Black.	F. Conchoidal.	3.5	6.70	1	Orthorh.
	Contains *silver*, but neither lead nor copper.—Gives a globule of silver when fused with borax and Na_2CO_3 on charcoal.	Matildite.	$Ag_2S.Bi_2S_3$.	Gray.	Gray.		2–3?	6.92	1–1.5?	Slender prisms.
Contains *lead*, but no bismuth.—With Na_2CO_3 on charcoal gives globules of lead and a yellow coating of lead oxide.	Oxidized by concentrated nitric acid with the separation of lead sulphate and usually, also, of some sulphur.	**GALENA.**	PbS.	Lead-gray.	Grayish-black.	C. Cubic, *per.*	2.5	7.6	2	Isometric, U. cryst. or gran.

☞ Compare *Cylindrite* and *Franckeite* (p. 250), which do not give very distinct antimony reactions.

Division 5.—**Sulphides.**—Continued on next page.

(Page 252.)

I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1-5, or Easily Volatile.

Division 5.—**Sulphides,** continued.

I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1—5, or Easily Volatile.

Division 5.—**Sulphides.**—Continued.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain *copper*, but do not give the reactions of the foregoing divisions.—The roasted minerals, moistened with HCl and heated B. B. on charcoal, impart an azure-blue color to the flame. The dilute HNO_3 solution is rendered blue by addition of ammonia in excess. This latter test must not be confounded with the somewhat similar one for nickel. When iron is present the blue color is not conspicuous until the ferric hydroxide precipitate has been filtered off.	Contain *iron*, and fuse to magnetic globules. — From the HNO_3 solution ammonia precipitates *ferric hydroxide*.	Color brass-yellow.—When massive, Cubanite can scarcely be told from Chalcopyrite except by a quantitative chemical analysis.	**CHALCOPYRITE.** (Copper Pyrites.)	$CuFeS_2$.	Brass-yellow.	Greenish-black.	F. Uneven.	3.5	4.2–4.3	2	Tet. Sph. Page 183.
			Cubanite.	$CuFe_2S_4$.	Bronze to brass-yellow.	Black.	C. Cubic, in traces.	4	4–4.5	2	Isometric.
		Color purplish, and somewhat variegated on exposed surfaces, but brownish-bronze on a fresh fracture. ☞ Compare *Chalcocite* below, which at times contains sufficient iron as an impurity to make it magnetic after heating.	**BORNITE.** (Variegated Copper, Peacock Ore.)	Cu_5FeS_4.	Brownish-bronze. Purplish tarnish.	Grayish-black.	F. Uneven.	3	4.9–5.4	2.5	Isometric. U. mass.
		Fused alone on charcoal the coal near the assay becomes covered with a white coating of oxide of tin. Only slightly magnetic after heating B.B.	**Stannite.** (Tin Pyrites.)	$Cu_2S.FeS.SnS_2$. Zn iso. w. Fe.	Steel-gray.	Black.	F. Uneven.	4	4.4	1.5	Massive.
	Contain *cobalt*.	The roasted minerals impart a blue color to the fluxes.	Carrollite.	$CuCo_2S_4$.	Light steel-gray.	Grayish-black	F. Uneven.	5.5	4.85	2	Isometric. U. mass.
			Sychnodymite.	$(Cu,Co)_4S_5$.	Steel-gray.				4.76		Isometric.
	Contain neither iron nor cobalt. Do not fuse to magnetic globules. ☞ Comp. *Stannite* above, which does not become magnetic except after long heating B. B.	From the HNO_3 solution *silver chloride* is precipitated by the addition of HCl.	**Stromeyerite.**	CuAgS.	Dark steel-gray.	Dark-gray.	F. Uneven.	2.5–3	6.2–6.3	1.5	Orthorh. U. mass.
		The finely powdered mineral, after careful roasting on charcoal (p. 40), gives in R. F. a globule of copper. Gives no sulphur in the closed tube.	**CHALCOCITE.** (Copper Glance.)	Cu_2S.	Steel-gray. Blackish tarnish.	Dark-gray.	F. Uneven.	2.5–3	5.7	2–2.5	Orthorh. Page 203. U. mass.
		Reacts like the foregoing, except that much sulphur is obtained by heating in the closed tube.	Covellite.	CuS.	Indigo-blue.	Grayish-black.	C. Basal, *per.*	1.5–2	4.6	2.5	Hexag. U. mass.
B. B. fuse to magnetic globules, due to the presence of either *iron, cobalt, or nickel.* When dissolved in HNO_3 iron imparts a yellowish, cobalt a rose, and nickel an apple-green color to the solution. Addition of ammonia in excess gives with iron a brownish-red precipitate of *ferric hydroxide*, and with nickel a blue solution (p. 97, § 3).	Contains *silver* and *iron*.	Fused with borax on charcoal in O. F. gives a globule of silver.	Sternbergite.	$AgFe_2S_3$.	Brownish-bronze.	Black.	C. Basal, *per.*	1–1.5	4.1–4.2	1.5	Orthorh.
	Contains *cobalt*. — The roasted mineral colors the borax bead blue.	Gives sulphur in the closed tube when heated intensely. Usually reacts for nickel when fused with borax on charcoal (p. 98).	**Linnæite.**	$(Co,Ni)_3S_4$. Fe and Cu iso. w. Co.	Pale steel-gray.	Grayish-black.	F. Uneven.	5.5	4.9	2	Isometric. Figs. 96 and 100.
	Contain *nickel*. —The roasted mineral colors the borax bead in O. F., violet when hot and reddish-brown when cold.	Give sulphur when heated intensely in the closed tube. Millerite occurs usually in capillary crystals, sometimes in velvety incrustations.	**Millerite.**	NiS.	Brass-yellow.	Black, somewhat greenish	C. Rhomboh. F. Uneven.	3–3.5	5.65	1.5–2	Hex. Rh.
			Polydymite.	Ni_4S_5.	Light- to steel-gray.	Grayish-black.	F. Uneven.	4.5	4.8	1.5–2	Isometric.
		In the HNO_3 solution ammonia produces an abundant precipitate of ferric hydroxide.	**Pentlandite.**	(Ni, Fe)S.	Yellowish-bronze.	Black.	Parting, oct. F. Uneven.	3.5–4	4.95–5.0	1.5–2	Isometric.
	Contains *zinc*.—Test as directed on p. 131 (Fig. 49).	After heating B. B., and volatilizing some of the zinc, the residue is slightly fusible and magnetic. Luster sub-metallic.	**SPHALERITE.** (Zinc Blende, Black Jack.)	(Zn, Fe)S. See pages 7 and 8.	Dark-brown to coal-black.	Light to dark-brown.	C. Dodecahedral, *per.*	3.5–4	4.05	5	Isom. Tet. Page 175.
	Contain only *iron* and sulphur.	Give little or no sulphur in the closed tube. Usually slightly magnetic before heating, but sometimes scarcely at all so. Troilite is found only in meteorites.	**PYRRHOTITE.** (Magnetic Pyrites.) Sometimes nickeliferous.	$Fe_{11}S_{12}$, perhaps FeS Ni iso. w. Fe. Test (p. 97, § 4).	Brownish-bronze.	Black.	Parting, basal. F. Uneven.	4	4.65	2.5–3	Hexag. Page 188. U. mass.
			Troilite.	FeS.	Brownish-bronze.	Black.	F. Uneven.	4	4.7–4.8	2.5–3	Massive.
		Give much sulphur in the closed tube. Are not magnetic before heating. Pyrite dissolves completely when 2 ivory-spoonfuls of its *very fine powder* are treated in a test-tube with 3 cc. of concentrated HNO_3, allowed to stand until vigorous action ceases, and then boiled. Marcasite when similarly treated yields some separated sulphur.*	**PYRITE.** (Iron Pyrites.)	FeS_2.	Pale brass-yellow.	Black, somewhat brownish.	F. Uneven.	6–6.5	4.95–5.1	2.5–3	Isom. Pyr. Page 173. U. cryst.
			MARCASITE. (White Iron Pyrites.)	FeS_2.	Pale-yellow to almost white. Yellowish tarnish.	Black, somewhat grayish.	F. Uneven.	6–6.5	4.85–4.9	2.5–3	Orthorh Tabular, pyram., prismatic.

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* The nitric acid for this experiment should be strong enough to act upon powdered pyrite energetically, and decompose it completely, even without the application of heat.

Division 5.—**Sulphides.**—Concluded on next page.

(Page 253.)

I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1-5, or Easily Volatile.

Division 5.—**Sulphides,** concluded.

Division 6.

I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1–5, or Easily Volatile.

Division 5.—Sulphides.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain *manganese*.—The roasted mineral imparts a reddish-violet color to the borax bead in O. F.	Gives little or no sulphur in the closed tube.	**Alabandite.**	MnS.	Iron-black. Brown tarnish.	Olive-green.	C. Cubic, *per.*	3.5–4	3.95	3	Isom. Tet. Cryst. rare
	Gives abundant sulphur in the closed tube.	Hauerite.	MnS_2.	Brown to brownish-black.	Reddish-brown.	F. Uneven.	4	3.46	3	Isom. Pyr. U. octahedrons.
Contains *mercury*.—Gives globules of the metal when heated in a closed tube with Na_2CO_3.	In the closed tube volatile, and gives a black sublimate of HgS. ☞ Compare *Cinnabar* (p. 258).	Metacinnabarite.	HgS.	Grayish-black.	Black.	F. Uneven.	3	7.8	Vol. 1.5	Isom. Tet.
Contains *germanium*.—When roasted on charcoal, transparent and white globules of *germanium oxide* collect near the assay, while farther out a lemon-yellow coating collects which has a peculiar glazed (fused) surface.		Argyrodite.	$4Ag_2S.GeS_2$. Hg iso. w. Ag & Sn w. Ge.	Black with bluish tone.	Grayish-black.	F. Uneven.	2.5	6.26	1.5–2	Isometric. U. mass.
Contains *tin*.—When fused on charcoal the globule and the coal near it become covered with a coating of oxide of tin, while a slight reaction for germanium may also be obtained.		Canfieldite.	$4Ag_2S.(Sn,Ge)S_2$.	Black with bluish tone.	Grayish-black.	F. Uneven.	2.5–3	6.27	1.5–2	Isometric.

Division 6.—Not belonging to the foregoing divisions.

The native metals.—Most of them are malleable, so that they can be beaten out into sheets by hammering on an anvil.	Soluble in boiling, dilute HNO_3 (1 part HNO_3 : 2 parts of water).	After fusing on charcoal the metal is bright, and no conspicuous coating of oxide is formed on the coal. From the HNO_3 solution HCl precipitates *silver chloride*. ☞ Compare *Amalgam*.	**SILVER.**	Ag. Occasionally with Au, Cu, and Hg.	Silver-white. Tarnish gray to black.	Silver-white, shiny.	F. Hackly.	2.5–3	10.5	2	Isometric. U. mass., acicular or in plates.
		The HNO_3 solution is made deep-blue by addition of ammonia in excess.	**COPPER.**	Cu.	Copper-red. Tarnish black.	Copper-red, shiny.	F. Hackly.	2.5–3	8.85	3	Isometric. U. mass.
		Easily fusible, and give yellow coatings of oxide on charcoal. When heated with potassium iodide and sulphur on charcoal, lead gives a greenish-yellow and bismuth a brilliant red sublimate. Bismuth is brittle.	Lead.	Pb.	Lead-gray.	Lead-gray, shiny.	F. Hackly.	1.5	11.37	1	Isometric.
			Bismuth.	Bi.	Silver-white.	Silver-white, shiny.	C. Basal and rhombohedral, *per.*	2–2.5	9.8	1	Hex. Rh. U. gran.
		B. B. on charcoal gives a coating of *zinc oxide*.	Zinc.	Zn.	Grayish-white.	Grayish-white, shiny.	C. Basal, *per.*	2	7.0	1.5	Hex. Rh.
		Heated in the closed tube globules of mercury are obtained. Mercury is wholly volatile, and amalgam leaves a residue of silver.	Mercury.	Hg.	Tin-white.				13.6		Liquid.
			Amalgam.	Hg with Ag.	Silver-white.	Silver-white, shiny.	F. Uneven.	3–3.5	13.7–14.1		Isometric.
	Insoluble in nitric acid.	Characterized by its color and high specific gravity.	**GOLD.**	Au, always with some Ag.	Gold-yellow.	Gold-yellow, shiny.	F. Hackly.	2.5–3	19.3 when pure.	2.5–3	Isometric. U. mass.
		Paler color than gold, and of lower specific gravity.	**ELECTRUM.**	Au with much Ag.	Yellowish-white.	Yellowish-white, shiny.	F. Hackly.	2.5–3	13–16	2–2.5	Isometric.
		Oxidized by HNO_3 yielding a white residue of *metastannic acid* (p. 126).	Tin.	Sn.	Tin-white.	Tin-white, shiny.	F. Hackly.	2	7.2	1	
Contain *iron*. — Are magnetic, or become *strongly so* after heating B. B. in R. F. ☞ Compare the *Silicates* and *Tungstates* in the next sections, and *Kentrolite* and *Longbanite* (p. 254), which may become slightly magnetic after heating.	*Anhydrous.*—Give little or no water in the closed tube. ☞ Compare *Ludwigite* (p. 268).	Strongly magnetic before heating. ☞ Compare *Titanic Iron* (p. 255).	**MAGNETITE.** (Magnetic Iron.)	$Fe_3O_4 = FeO + Fe_2O_3$.	Iron-black.	Black.	F. Uneven. Parting oct.	6	5.18	5–5.5	Isometric.
		Characterized by its reddish-brown streak. Slightly or not at all magnetic before heating.	**HEMATITE.** (Specular Iron.)	Fe_2O_3.	Dark steel-gray to iron-black.	Dark reddish-brown, Indian-red.	F. Uneven. Parting rhombohedral.	5.5–6.5	5.20	5–5.5	Hex. Rh. Page 194.
		Imparts a green color to the Na_2CO_3 bead in O. F. (*manganese*).	Bixbyite.	$FeMnO_3 = FeO.MnO_2$.	Black.	Black.	F. Uneven.	6–6.5	4.94	4.5	Isometric.
		Gives globules of lead when fused with Na_2CO_3 on charcoal.	Melanotekite.	$(Fe'''_4O_3)Pb_3(SiO_4)_3$	Dark brown to black.	Yellowish-brown.	F. Uneven.	5–5.5	5.85	2–2.5	Orthorh. Prismatic.
	Hydrous. — Give water in the closed tube.	Difficultly fusible. Turgite generally decrepitates, and breaks up to a fine powder in the closed tube. Göthite generally crystallizes in prismatic forms.	**TURGITE.** (Hydro-hematite.)	$Fe_4O_5(OH)_2 = 2Fe_2O_3 + H_2O$.	Reddish-black	Dark reddish-brown.	F. Splintery.	5.5–6	4.14	5–5.5	Botryoid. Incrust.
			GOETHITE.	$FeO(OH) = 2Fe_2O_3 + 2H_2O$.	Dark-brown to black.	Yellowish-brown.	C. Pinac., *per.*	5–5.5	4.35	5–5.5	Orthorh.
			LIMONITE. (Brown Hematite.)	$Fe_4O_3(OH)_6 = 2Fe_2O_3 + 3H_2O$.	Dark-brown to black.	Yellowish-brown.	F. Splintery.	5–5.5	3.6–4.0	5–5.5	Botryoid. Stalactitic

Division 6.—Concluded on next page.

(Page 254.)

I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

A.—Fusible from 1-5, or Easily Volatile.

Division 6, concluded.

A.—Fusible from 1–5, or Easily Volatile.

DIVISION 6.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Silicates.—Ilvaite and Allanite are decomposed by HCl, and yield *gelatinous silica* upon evaporation. Neptunite is insoluble in HCl, but may be tested for a silicate as directed on p. 110, §4. N.B.—These silicates have a pitchy or resinous luster, and they, as well as others which are black owing to the presence of iron, are more properly classified in subsequent sections under *minerals without metallic luster*. ☞ Compare *Melanotekite*, *Kentrolite*, and *Braunite*, of this division.	Intumesces slightly when fused B. B. The globule is decidedly magnetic.	**Ilvaite.** (Lievrite.)	$CaFe''_2(Fe'''.OH)(SiO_4)_2$.	Iron-black.	Black.	F. Uneven.	5.5–6	4.05	2.5	Orthorh. U. prism.
	Intumesces strongly when fused B. B. The globule is sometimes magnetic. Gives reactions for the *rare-earth metals* (p. 65).	**Allanite.**	$R''_2(R'''.OH)R'''_2(SiO_4)_3$. R''=Ca and Fe. R'''=Al, Fe, Ce, La, and Di.	Brown to pitch-black.	Gray.	F. Uneven to conchoidal.	5.5–6	3.5–4.2	2.5	Monocl. U. mass.
	Fuses B. B. to a black globule and colors the flame yellow. Reacts for *titanium* when tested as directed on p. 127, §2.	Neptunite.	$(Na,K)(Fe,Mn)TiSi_4O_{12}$.	Black.	Cinnamon-brown.	C. Prismatic. F. Conchoidal.	5–6	3.23	3–4	Monocl.
Contain *tungsten.*—Fuse with Na_2CO_3, pulverize the fusion, digest with boiling water, and filter. The filtrate made acid with HCl and boiled with tin assumes a blue color (p. 129, §2). The high specific gravity is noticeable.	Imparts to the Na_2CO_3 bead in O. F. a green color (*manganese*). Fused on charcoal with a little Na_2CO_3 yields a magnetic mass.	**WOLFRAMITE.** Compare *hübnerite*, p. 283.	$(Fe,Mn)WO_4$.	Black.	Black.	C. Pinac., *per.* F. Uneven.	5–5.5	7.2–7.5	3–3.5	Monocl. U. cryst.
	Contains little or no manganese. Fusible B. B. to a magnetic mass.	Wolframite, in part.	$FeWO_4$.	Black.	Black.	C. Pinac., *per.*	5–5.5	7.2–7.5	3–3.5	Monocl.
		Reinite.	$FeWO_4$.	Blackish-brown.	Brown.	F. Uneven.	4	6.64	3–3.5	Tetrag.
Contain *niobium.*—Fused with borax, then dissolved in HCl and boiled with tin, the solution assumes a blue color (p. 99, §1). The high specific gravity is noticeable.	Reacts for *iron* and usually also for *manganese* when tested as directed above for wolframite.	**COLUMBITE.**	$(Fe,Mn)(Nb,Ta)_2O_6$.	Iron-black.	Black.	F. Uneven.	6	5.3–7.0	5–5.5	Orthorh. U. cryst.
	React for *uranium* and the *rare-earth metals* when tested as directed on p. 129, §2, and p. 65.	Samarskite.	$R''_3R'''_2(Nb,Ta)_6O_{21}$ R''=Fe, Ca, UO_2; R'''=Ce and Y earths.	Velvet-black.	Dark reddish-brown.	F. Conchoidal.	5–6	5.6–5.8	4.5–5	Orthorh. U. mass.
		Aannerödite. (Onnerödite.)	Uncertain. Nb, U, Y, Th, Ce, Pb, Fe, Ca, H, O.	Black.	Brown to blackish brown.	F. Uneven.	6	5.7	4.5	Orthorh.
Contain *copper.*—B. B. alone, or with Na_2CO_3, on charcoal, give a globule of copper. After moistening with HCl impart azure-blue and green colors to the blowpipe flame (p. 72, §1).	Characterized by its sub-metallic luster and red streak (see p. 263).	**CUPRITE.**	Cu_2O.	Deep-red.	Brownish-red, Indian-red.	F. Conchoidal or uneven.	3.5–4	6.0	2.5–3	Isometric. Cl. 4. p. 219
	Tenorite crystallizes in scales; paramelaconite in prisms.	Tenorite. (Melaconite.)	CuO.	Steel- to iron-gray.	Grayish-black.	C. Basal, *per.* F. Uneven.	3–4	5.8–6.2	3	Monocl. Massive.
		Paramelaconite.	CuO?	Purplish- to pitch-black.		F. Uneven.	5	5.83	3	Tetrag.
Contains *lead.*—With Na_2CO_3 on charcoal gives globules of the metal and a coating of lead oxide.	When heated in the closed tube yields fusible lead oxide and oxygen gas. Test as directed on p. 100, §1.	Plattnerite.	PbO_2.	Iron-black.	Chestnut-brown.	F. Uneven.	5–5.5	8.5	1.5	Tetrag. U. mass.
	Imparts a reddish-violet color to the borax bead in O. F. (*manganese*). Compare *Melanotekite.*	Kentrolite.	$(Mn'''_4O_3)Pb_3(SiO_4)_3$. Fe iso. w. Mn.	Black.	Brown.	F. Uneven.	5–5.5	6.19	2–2.5	Orthorh.
Contain *manganese,* but do not give the reactions of the foregoing sections.—Impart to the borax bead in O. F. a reddish-violet color.	The fine powder is slowly soluble in HCl. Yields a small amount of gelatinous silica on evaporation.	**Braunite.**	$MnMnO_3$ with a little $MnSiO_3$.	Black.	Brownish-black.	C. Pyramidal. F. Uneven.	6–6.5	4.8	4.5–5	Tetrag. Fig. 143, page 178.
	Gives a slight coating of oxide of antimony when heated with Na_2CO_3 on charcoal.	Laangbanite. (Longbanite.)	Uncertain. Mn, Fe, Si, and Sb oxides.	Iron-black.	Dark reddish-brown.	F. Uneven.	6.5	4.92	4.5	Hex. Rh.

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I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

B.—Infusible or Fusible above 5, and Non-volatile.

Division 1.—**Iron Compounds.**

B.—Infusible, or Fusible above 5, and Non-volatile.

DIVISION 1.—**Iron Compounds.**—Strongly attracted by a magnet after being heated before the blowpipe in the reducing flame (the test must not be made while the fragment is hot, p. 84, § 1).

N.B.—The minerals in this division are chiefly the *oxides* and *hydroxides of iron*. Several of them are important as ores of the metal. Generally they dissolve in hydrochloric acid, though often slowly. The solutions, after dilution with water, may be tested for *ferrous* and *ferric iron* with potassium ferri- and ferrocyanides, as directed on p. 85, § 4.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Strongly magnetic without heating. Malleable. ☞ Compare platinum (p. 257).	When treated as directed on p. 97, § 4, meteoric iron has *always*, and terrestrial irons have often, reacted for *nickel*.	Iron. (Meteoric Iron.)	Fe, also Fe with Ni.	Steel-gray.	Steel-gray.	C. Cubic. F. Hackly.	4–5	7.3–7.5	Isometric. U. mass.
	Characterized by containing much nickel.	Awaruite.	$FeNi_2$.	Steel-gray.	Steel-gray.	F. Hackly.	5	8.1	Massive.
Strongly magnetic without heating. Brittle.	Very slowly attacked by HCl. Reacts for *titanium* (p. 127, § 2).	**ILMENITE** (Titanic Iron, in part.)	$FeTiO_3$ with Fe_2O_3 in varying proportions.	Iron-black.	Black.	F. Uneven.	5.5–6	4.7–5.1	Hex. Rh. U. mass.
	The fine powder is slowly, but completely, soluble in HCl. The solution reacts for both ferrous and ferric iron. Fus. = 5–5.5.	**MAGNETITE.**	$Fe_3O_4 = FeO.Fe_2O_3$.	Iron-black.	Black.	Parting octahedral. F. Uneven.	6	5.18	Isometric. Figs. 96, 97 & 102.
	Reacts for *magnesium* when tested as directed on p. 91, § 1, b.	Magnesioferrite.	$MgFe_2O_4 = MgO.Fe_2O_3$.	Iron-black.	Black.	F. Uneven.	6–6.5	4.6	Isometric.
Contains *titanium*.—After fusion with Na_2CO_3 the material can be dissolved by HCl, and the solution when boiled with tin becomes violet (p. 127, § 2).	Gives a coating of oxide of antimony when fused with Na_2CO_3 on charcoal.	Derbylite.	$5FeTiO_3.FeSb_2O_6$.	Pitch-black.	Brown.	F. Conchoidal.	5	4.53	Orthorh.
	Distinguished by differences in crystallization and physical properties.	**ILMENITE.** (Titanic Iron.)	$FeTiO_3 = FeO.TiO_2$. Mg iso. w. Fe.	Iron-black.	Black.	F. Uneven.	5.5–6	4.7	Hex. Rh. Page 197.
		Pseudobrookite.	$Fe_4(TiO_4)_3$.	Brownish-black.	Yellowish- or reddish-brown	F. Uneven.	6	4.98	Orthorh.
Contain *manganese*.—Impart to the Na_2CO_3 bead in O. F. a green or bluish-green color.	Gives a coating of *oxide of zinc* when the *very fine powder*, mixed with a little Na_2CO_3, is heated intensely on charcoal.	**FRANKLINITE.**	$(Fe,Zn,Mn)O.(Fe,Mn)_2O_3$. Fe_3O_4 with Zn and Mn iso. w. Fe	Iron-black.	Dark-brown.	F. Uneven.	6	5.15	Isometric. Figs. 96 and 102.
	Gives a coating of *oxide of antimony* when treated as above.	Melanostibian.	$6(Fe,Mn)O.Sb_2O_3$.	Black.	Cherry-red.	C. Two directions, 90°.	4		Orthorh.?
	Does not give the foregoing reactions.	Jacobsite.	$(Mn,Mg)O.(Fe,Mn)_2O_3$.	Black.	Brownish-black.	F. Uneven.	6	4.75	Isometric.
Give water in the closed tube. Difficultly fusible. Fus. = 5–5.5:	Water about 5%. Generally decrepitates violently when heated in the closed tube.	**Turgite** (Hydro-hematite.)	$Fe_4O_5(OH)_2 = 2Fe_2O_3.H_2O$	Black to reddish-black.	Brownish-red, Indian-red.	F. Splintery.	5.5–6	4.14	Massive. Mammill.
	Water about 10%. Generally crystallized in prisms.	**GOETHITE.**	$FeO(OH) = 2Fe_2O_3.2H_2O$.	Dark-brown to black.	Yellowish-brown, yellow-ocher.	C. Pinacoidal, *perfect*.	5–5.5	4.35	Orthorh. Prismatic.
	Water about 15%. Mammillary and stalactitic (p. 222). Often impure. Distinct crystals unknown.	**LIMONITE.** (Brown Hematite.)	$Fe_4O_3(OH)_6 = 2Fe_2O_3.3H_2O$.	Dark-brown to nearly black.	Yellowish-brown, yellow-ocher.	F. Splintery.	5–5.5	3.6–4.0	Orthorh. U. fibrous.
Give little or no water in the closed tube. Daubréelite reacts for sulphur when roasted in an open tube. ☞ Compare *Tripuhyite* (p. 263).	Streak brownish-red (Indian-red, red-ocher). Sometimes slightly magnetic before heating. Fus. = 5–5.5.	**HEMATITE.** (Specular Iron.)	Fe_2O_3.	Steel-gray to iron-black.	Brownish-red. Indian-red.	F. Uneven, scaly, fibrous.	5.5–6.5	5.20	Hex. Rh. Page 194.
	Imparts a green color to the salt-of-phosphorus bead (*chromium*). Compare *Chromite* (p. 256).	Daubréelite. (Meteoric only.)	$FeS.Cr_2S_3$.	Black.	Black.	C. One direc.		5.01	Massive. Scaly.

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I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

B.—Infusible, or Fusible above 5, and Non-volatile.

Division 2.—Manganese Compounds.

Division 3, in part.

B.—Infusible, or Fusible above 5, and Non-volatile.

DIVISION 2.—**Manganese Compounds.**—A trifling quantity of the material will impart to the borax bead in the oxidizing flame a reddish-violet or amethystine color. The green color which manganese compounds impart to the sodium-carbonate bead in the oxidizing flame is also a very delicate and decisive test.

N.B.—The minerals in this division are chiefly *oxides of manganese*. They dissolve in hydrochloric acid with evolution of chlorine gas (p. 101, § 2), and many of them yield oxygen gas when heated in a closed tube (p. 100, § 1).

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Give little or no water when heated in the closed tube. ☞ Compare *Pinakiolite* (p. 277).	Contains *copper*, and imparts to the blowpipe flame a blue or green color after moistening with HCl.	Crednerite.	$Cu_3Mn_4O_9$.	Iron-black.	Brownish-black.	C. Basal, *per*.	4.5	4.98	Monocl. Foliated.
	Reacts for *titanium* when tested as directed on p. 129, § 2.	Pyrophanite.	$MnTiO_3 = MnO.TiO_2$.	Deep-red.	Ocher-yellow.	C. Rhombohedral, *per*.	5	4.54	Hex. Rh. Cl. 14. p. 219.
	Give oxygen gas when heated in the closed tube (p. 100, § 1). Pyrolusite is perhaps always a pseudomorph after other minerals (often after manganite). It is soft, and contains about 2 per cent of water.	Polianite.	MnO_2.	Steel-gray.	Black.	C. Prismatic, *perfect*.	6–6.5	5.0	Tetrag.
		PYROLUSITE.	MnO_2 with about 2% H_2O.	Iron-black.	Black.	F. Splintery.	2–2.5	4.75	Massive. Pseudom.
	Do not give oxygen gas when heated in the closed tube (p. 100, § 1). Finely pulverized braunite is slowly decomposed by HCl, and the solution yields gelatinous silica upon evaporation.	**Braunite.**	$MnMnO_3$ with a little $MnSiO_3$	Black.	Brownish-black.	C. Pyramidal. F. Uneven.	6–6.5	4.8	Tetrag. Fig. 143.
		Hausmannite.	Mn_3O_4.	Black.	Chestnut-brown.	C. Basal. F. Uneven.	5–5.5	4.8	Tetrag.
Give much water when heated in the closed tube. ☞ Compare *Asbolite* and *Wad* (p. 292).	The prismatic crystallization and dark-brown streak are characteristic. Compare *Pyrolusite*.	**MANGANITE.**	$MnO(OH) = Mn_2O_3.H_2O$.	Steel-gray to iron-black.	Dark-brown.	C. Pinacoidal, *perfect*.	4	4.31	Orthorh. Prismatic.
	B. B. on charcoal gives a coating of *oxide of zinc*.	Chalcophanite.	$(Mn,Zn)Mn_2O_5.H_2O$.	Bluish-black.	Dark chocolate-brown.	C. Basal, *per*.	2.5	4.0	Hex. Rh.
	Does not crystallize. The HCl solution generally gives a white precipitate of barium sulphate upon addition of H_2SO_4.	**PSILOMELANE.**	Uncertain. MnO_2 with MnO, H_2O, and often BaO and K_2O.	Iron-black.	Brownish-black.	F. Uneven.	5–6	About 4.3	Massive.

DIVISION 3.—Not belonging to the foregoing divisions.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Very soft. Readily mark paper and soil the fingers.	Heated B. B. in the forceps colors the flame yellowish-green. Roasted in the open tube gives the reactions for a sulphide and for molybdenum (p. 95).	**MOLYBDENITE.**	MoS_2.	Lead-gray.	Grayish-black.	C. Basal, *per*.	1–1.5	4.75	Hexag.? Foliated.
	Does not give the foregoing reactions. Very refractory.	**GRAPHITE.** (Black Lead.)	C.	Iron-black.	Black.	C. Basal, *per*.	1–1.5	2.20	Hex. Rh. Foliated.
Contains *chromium*.—Imparts a green color to the borax and salt of phosphorus beads.	Finely powdered chromite mixed with Na_2CO_3, in equal proportions, and intensely heated on charcoal, gives a mass which is attracted by a magnet (*iron*). Magnesian-chromite may contain too little iron to give the foregoing reaction.	**CHROMITE.** (Chromic Iron.)	Essentially $FeCr_2O_4 = FeO.Cr_2O_3$.	Iron-black to brownish-black.	Dark-brown.	F. Uneven.	5.5	4.6	Isometric. U. mass.
		Magnesian-chromite.	$FeCr_2O_4$ with $MgAl_2O_4$.	Brownish-black.	Brown.	F. Uneven.	5.5	4.2	Isometric. U. mass.

DIVISION 3.—Concluded on next page.

(Page 257.)

I. MINERALS WITH METALLIC OR SUB-METALLIC LUSTER.

B.—Infusible, or Fusible above 5, and Non-volatile.

DIVISION 3, concluded.

B.—Infusible, or Fusible above 5, and Non-volatile.

Division 3.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Streak.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Contain *titanium*.—Fused with borax, then dissolved in HCl and boiled with tin, the solution becomes violet (p.127, § 2). ☞ Compare *Rutile, Octahedrite,* and *Brookite* (p. 299), which sometimes are black and have a sub-metallic luster.	After the violet color of titanium has been obtained, by continued boiling with tin the solution finally assumes a blue color (*niobium*, p. 99, § 1). ☞ Compare *Polymignite*, below.	Dysanalyte.	$CaTiO_3$, with some $(Fe,Ca)Nb_2O_6$ and rare-earth metals. Formula uncertain.	Black.	**Gray.**	C. Cubic. F. Uneven.	5–6	4.18	Isometric. Cubes & Octahedrons.
	Fused with the acid sulphate of potash and fluorspar mixture, momentarily colors the flame green (*boron*). Fus. = 5.5	Warwickite.	$(Mg,Fe)_4B_2TiO_9$?	Dull-black.	Black.	C. One direction, *per*. F. Uneven.	3–4	3.35	Orthorh. Prismatic.
	A little of the fine powder mixed with an equal volume of Na_2CO_3 and fused intensely in charcoal gives a mass which is attracted by a magnet (see p. 255).	**ILMENITE.** (Magnesian Variety.)	$(Mg,Fe)TiO_3 = (Mg,Fe)O.TiO_2$.	Iron-black.	Black.	F. Uneven.	5.5–6	4.30	Hex. Rh. Page 197.
		Pseudobrookite.	$Fe_4(TiO_4)_3$.	Brownish-black.	Yellowish- or reddish-brown	F. Uneven.	6	4.98	Orthorh.
	After fusing with Na_2CO_3 and dissolving in HCl the titanium may be precipitated by ammonia. In the filtrate *calcium* may be detected by ammonium oxalate, and *magnesium* by sodium phosphate.	**Perovskite.** (Perofskite.)	$CaTiO_3$.	Brown to black.	Grayish.	F. Uneven.	5.5	3.95	Isometric.
		Geikielite.	$MgTiO_3$. Fe iso. w. Mg.	Blue-black.		C. Perfect.	6.5	3.98	Hex. Rh.?
Contain *niobium*.—Fused with borax, then dissolved in HCl and boiled with tin, the solution assumes a blue color (p. 99, § 1). The high specific gravity is noticeable. ☞ Compare the difficultly fusible niobium minerals on p. 254, and those with resinous to sub-metallic luster on pp. 298 and 300.	Generally imparts to the Na_2CO_3 bead in O. F. a green color (*manganese*). Fused on charcoal with a little Na_2CO_3 yields a magnetic mass. For variations in specific gravity see p. 7.	**COLUMBITE.**	Essentially $(Fe,Mn)Nb_2O_6$, with $(Fe,Mn)Ta_2O_6$.	Black.	Dark-red to black.	F. Uneven.	6	5.3–6.5	Orthorh. U. prism.
		Mossite.	$Fe(Nb,Ta)_2O_6$.	Black.	Black.	F. Uneven.	6	6.45	Tetrag.
	In making the reduction test with zinc the violet color of *titanium* appears before the blue of niobium (p. 99, § 2).	Polymignite.	Uncertain. Nb, Zr, Ti, Ca, Th, Ce, Y, Fe''', Fe'', O.	Black.	Dark-brown.	F. Conchoidal.	6.5	4.8	Orthorh.
Contain *tantalum* (p. 123), but give no, or only slight, reactions for niobium. Characterized by exceptionally high specific gravity.	React for iron and sometimes, also, for manganese when tested as directed above for columbite.	Tantalite.	$(Fe,Mn)Ta_2O_6$. Nb iso. w. Ta.	Black.	Black.	F. Uneven.	6	6.5–7.3	Orthorh.
		Tapiolite.	$FeTa_2O_6$. Nb iso. w. Ta.	Black.	Black.	F. Uneven.	6	7.3–7.8	Tetrag.
	Give reactions for *tin* and *uranium* when tested as directed on pp. 126, § 3, and 129, § 2.	Hielmite.	Uncertain. Ta, Nb, Sn, U, Y, Ce, Fe'', Mn, Ca, H, O.	Black.	Grayish black.	F. Uneven.	5	5.8	Orthorh.
Contains *uranium*.—Imparts to the salt of phosphorus bead in O. F. a yellowish-green and in R. F. a green color.	Soluble in dilute H_2SO_4 with the slight evolution of a gas (*helium*). The high specific gravity is noticeable.	**Uraninite.** (Pitch Blende.)	Uncertain. UO_3, UO_2, Th, Y, Pb, and He.	Black.	Brownish-black.	F. Uneven.	5.5	9–9.7	Isometric. U. mass.
Compare Baddeleyite, ZrO_2 (p. 302).		Baddeleyite.	ZrO_2.						
Contain *platinum* or the metals of the *platinum group* (pp. 103 and 104).—These minerals are characterized by exceptionally high specific gravities, and by their insolubility in any single acid.	Gives sulphur dioxide when roasted in the open tube. ☞ Compare *Sperrylite*, p. 247.	Laurite.	RuS_2. Os iso. w. Ru.	Iron-black.	Dark-gray.	C. Octahedral. F. Conchoidal.	7.5	7.0	Isometric.
	Malleable. B. B. unaltered. Sometimes magnetic.	**Platinum.**	Pt, with Fe and the rare platinum metals.	Whitish steel-gray.	Gray, shiny.	F. Hackly.	4–4.5	14–19	Isometric.
	Malleable. Loses its tarnish when heated B. B. in R. F., but regains it by heating in the open tube.	Palladium.	Pd, with Pt and Ir.	Whitish steel-gray.	Gray, shiny.	F. Hackly.	4–4.5	11.3–11.8	Isometric.
	Slightly malleable to brittle. Heated in the open tube gives the odor of osmium oxide.	Iridosmine.	Ir, with Os, Rh, and Pt.	Tin-white.	Gray.	C. Basal, *per*.	6–7	19–21	Hex. Rh.
	Does not react for osmium.	Iridium.	Ir, with Pt.	Tin-white.	Gray.	F. Hackly.	6–7	22.7	Isometric.

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II. MINERALS WITHOUT METALLIC LUSTER.

A.—Easily Volatile or Combustible.

A.—Easily Volatile, or Combustible.

N.B.—The few minerals which are included in this section entirely disappear when heated B. B., provided they are pure. It may be recommended to heat a small fragment B. B. alone on charcoal, or still better in most cases in a closed tube, when the material should *volatilize completely* and condense as a sublimate. It is not an indication that a mineral is volatile if it decrepitates, or falls to a fine powder when heated, and therefore cannot be retained in the platinum forceps nor on charcoal.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage or Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Burns with a blue flame and gives the strong odor of sulphur dioxide.	The sublimate in the closed tube is a red to dark yellow liquid when hot, a pale yellow solid when cold.	**SULPHUR.**	S.	Pale yellow.	Resinous.	F. Conchoidal or uneven.	1.5–2.5	2.07	1	Orthorh. Page 202.
Contain *arsenic.*—Yield the volatile, crystalline sublimate of *arsenious oxide* when heated in the open tube (sulphides must be roasted very slowly and carefully). An arsenical mirror may be obtained by mixing the mineral with six volumes of dry Na_2CO_3 and a little charcoal powder and heating in a closed tube (p. 51, § 1, *b*).	Imparts a decided green color to the blowpipe flame (*thallium*).	Lorandite.	$TlAsS_2 = Tl_2S.As_2S_3$.	Carmine-red.	Adamantine.	C. One direction, *perfect.*	2–2.5	5.53	1	Monocl.
	The sublimate in the closed tube is a deep-red, almost black liquid when hot, a reddish-yellow, transparent solid when cold.	**REALGAR.**	AsS.	Aurora-red.	Resinous.	C. Pinacoidal. F. Conchoidal.	1.5–2	3.55	1	Monocl. U. cryst.
		ORPIMENT.	As_2S_3.	Lemon-yellow.	Pearly, resinous.	C. Pinacoidal, *perfect.*	1.5–2	3.48	1	Monocl. U. foli.
	Yield the white crystalline sublimate of arsenious oxide when heated in a closed tube. Volatile with only a slight tendency to fuse.	Arsenolite.	As_2O_3.	Colorless to white.	Adamantine.	F. Uneven.	1.5	3.70	Vol. 1	Isometric.
		Claudetite.	As_2O_3.	Colorless to white.	Pearly.	C. Pinacoidal, *perfect.*	2.5	3.9–4.1	Vol. 1	Monocl. Tabular.
Contain *antimony.* — B. B. on charcoal fuse and coat the coal with a dense white sublimate of the oxides of antimony.	In the open tube gives sulphur dioxide.	**Kermesite.**	Sb_2S_2O.	Brownish-red, maroon.	Adamantine.	C. Pinacoidal, *perfect.*	1–1.5	4.60	1	Monocl. Acicular.
	Fuse easily when heated in the closed tube, and give a slight white sublimate consisting often of prisms and octahedrons of Sb_2O_3.	**Senarmontite.**	Sb_2O_3.	Colorless or white.	Adamantine.	F. Uneven.	2–2.5	5.25	1.5	Isometric. Fig. 96.
		Valentinite.	Sb_2O_3.	Colorless or white.	Pearly, adamantine.	C. Pinac., *per.* and prismatic.	2.5–3	5.56	1.5	Orthorh. Prismatic
Contain *ammonium.*—Give the odor of ammonia when heated in a closed tube with lime (ignited calcite), or boiled in a test-tube with potassium hydroxide.	Volatile without fusion. The aqueous solution gives a precipitate with silver nitrate.	Sal-ammoniac.	NH_4Cl.	Colorless or white.	Vitreous.	F. Conchoidal.	1.5–2	1.53	Vol. 1	Isometric. Cl. 4, p. 219
	Fusible. The aqueous solution gives a precipitate with barium chloride.	Mascagnite.	$(NH_4)_2SO_4$.	Colorless or white.	Vitreous.	F. Uneven.	2–2.5	1.77	1	Orthorh.
Contain *mercury.*—Give a sublimate of mercury when heated in a closed tube with dry sodium carbonate (p. 94, § 1).	Streak red. Gives sulphur dioxide and mercury in the open tube (p. 94, § 2). Gives a black sublimate (HgS) in the closed tube.	**CINNABAR.**	HgS.	Red. Vermilion.	Adamantine.	C. Prismatic, *perfect.* F. Uneven.	2–2.5	8.10	Vol. 1.5	Hex. Rh. Class 15, p. 219.
	After testing for the mercury with Na_2CO_3, the contents of the tube, when dissolved in water and HNO_3, will give a precipitate with silver nitrate.	Calomel.	HgCl.	Colorless or white.	Adamantine.	F. Conchoidal.	1–2	6.48	Vol. 1	Tetragonal.
Contains *lead.*—Gives a globule of the metal and a coating of oxide when fused with Na_2CO_3 on charcoal.	Quite soluble in hot water. On cooling, the solution deposits lead chloride.	Cotunnite.	$PbCl_2$.	Colorless or white.	Adamantine.	F. Uneven.	1–2	5.80	1	Orthorh.
Contain *sodium* or *potassium.*—Color the blowpipe flame yellow or violet, respectively.	After ignition B. B. the residue imparts an alkaline reaction to turmeric paper.	A number of the minerals containing the alkali metals are wholly volatile if heated for a considerable time. They will be found, however, among the fusible minerals on p. 271.								

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

Part I.—Give a metallic globule when fused with sodium carbonate on charcoal.

Division 1.—**Silver Compounds.**

Division 2.—**Lead Compounds,** in part.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

Part I.—Give a metallic globule when fused with sodium carbonate on charcoal.

Division 1.—**Silver Compounds.**—A globule of silver is obtained by fusing on charcoal with sodium carbonate. When antimony is present, some of it will alloy with the silver and the globule will be brittle.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain *sulphur.*—Heated in the open tube yield sulphur dioxide and the oxides of either arsenic or antimony. If the globule obtained by heating on charcoal with Na_2CO_3 is brittle, it may be converted to pure silver by heating in O. F. with borax. ☞ Compare *Miargyrite* and *Polybasite* (p. 250).	When heated in the closed tube readily yield an abundant sublimate of sulphide of arsenic, deep red, almost black when hot, reddish-yellow when cold (p. 140), and beyond this a slight sublimate of sulphur.	**Proustite.** (Ruby Silver.)	$3Ag_2S.As_2S_3$.	Ruby-red.	Adamantine.	F. Conchoidal.	2–2.5	5.55	1	Hex. Rh. Hemimor.
		Xanthoconite. (Rittingerite.)	$3Ag_2S.As_2S_3$.	Orange-yellow to clove-brown	Adamantine.	C. Basal.	2	5.54	1	Monocl. Tabular.
	Upon intense and prolonged heating in the closed tube a slight sublimate of oxysulphide of antimony deposits where the glass is very hot. This is black when hot, reddish-brown when cold (p. 45, § 3), and beyond it there is a slight deposit of sulphur.	**Pyrargyrite.** (Dark-red Silver Ore.)	$3Ag_2S.Sb_2S_3$.	Dark-red to black.	Adamantine.	F. Conchoidal.	2.5	5.85	1	Hex. Rh. Hemimor.
		Pyrostilpnite. (Fireblende.)	$3Ag_2S.Sb_2S_3$.	Hyacinth-red.	Adamantine.	C. Pinacoidal.	2	4.3?	1	Monocl. Tabular.
Contain *chlorine, bromine,* or *iodine.*—Sublimates of the *chloride, bromide,* or *iodide of lead* are obtained by heating with galena in a closed tube as directed on p. 68, § 4. The chloride and bromide are *sectile* and can be cut with a knife like horn.	The sublimate (*lead chloride*) is white, both when hot and cold.	**Cerargyrite.** (Horn Silver.)	AgCl.	Pearl-gray to colorless.	Adamantine.	F. Uneven or hackly.	2–3	5.8–6.0	1	Isometric.
	The sublimate (*lead bromide*) is sulphur-yellow when hot, but white when cold. The chlorine in embolite may be detected as directed on p. 69, § 5.	**Embolite.**	Ag(Cl,Br).	Green or yellow.	Adamantine.	F. Uneven.	2–3	5.80	1	Isometric.
		Bromyrite.	AgBr.	Green or yellow.	Adamantine.	F. Uneven.	2–3	5.8–6.0	1	Isometric.
	The sublimate (*lead iodide*) is dark orange-red when hot, lemon-yellow when cold. Cuproiodargyrite may be identified by its reactions for copper.	Miersite.	AgI. Cu iso. w. Ag.	Yellow.	Adamantine.		2		1	Isom. Tet.
		Iodyrite.	AgI.	Lemon-yellow	Resinous.	C. Basal. F. Uneven.	1.5	5.70	1	Hexag. Page 190.
		Iodobromite.	Ag(Cl,Br,I).	Sulphur-yellow to green.	Resinous.	F. Uneven or hackly.	2–3	5.70	1	Isometric.
		Cuproiodargyrite.	AgI.CuI.	Sulphur-yellow.			2			Massive.

Division 2.—**Lead Compounds.**—*Globules of lead* and a *yellow coating of lead oxide* are easily obtained by fusion on charcoal with sodium carbonate and a little charcoal powder. Bismuth gives a very similar reaction, but the globules of bismuth are brittle. The pale azure-blue flame coloration, and the conspicuous iodine tests for lead (p. 89), can be recommended. For the solution of lead minerals *dilute nitric acid* (1 part HNO_3 to 2 of water) should be used, and in the solutions hydrochloric and sulphuric acids will give precipitates of *lead chloride* and *lead sulphate,* respectively.

N.B.—The various salts of lead will be found in this division, with the exception of those compounds (mostly sulphides) which have a metallic luster.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Carbonates.—Soluble in warm *dilute* acids with evolution of carbon dioxide (effervescence). Generally it is best to employ dilute HNO_3, but for Leadhillite use dilute HCl.	Heated in the closed tube a sublimate of *lead chloride* is obtained, which fuses to colorless globules.	Phosgenite.	$(PbCl)_2CO_3 = PbCO_3.PbCl_2$.	Colorless or white.	Adamantine.	C. Basal and prismatic.	3	6.2	1	Tetrag. U. cryst.
	The *dilute* HCl solution gives with barium chloride a precipitate of barium sulphate. Gives a little water in the closed tube.	Leadhillite.	$Pb_2(Pb.OH)_2(CO_3)_2SO_4 = 2PbCO_3.(Pb.OH)_2SO_4$.	Colorless or white.	Pearly, adamantine.	C. Basal, *per.* F. Uneven.	2.5	6.54	1.5	Monocl. U. cryst.
	Gives water in the closed tube, but does not react for a sulphate.	Hydrocerussite.	$Pb(Pb.OH)_2(CO_3)_2$.	Colorless or white.	Pearly.		1–2	6.14	1.5	Hexag. Tabular.
	Gives none of the above reactions. In the closed tube, usually decrepitates and is changed to lead oxide, which is dark yellow when hot.	**CERUSSITE.**	$PbCO_3$.	Colorless or white.	Adamantine.	F. Conchoidal.	3–3.5	6.55	1 5	Orthorh. Page 206.

Division 2.—**Lead Compounds.**—Continued on next page.

(Page 260.)

II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 2.—**Lead Compounds,** continued.

B.—Fusible from 1–5, and Non-volatile or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 2.—Lead Compounds.—Continued.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Sulphates.—When mixed with Na_2CO_3 and a little charcoal powder, and fused in R. F. on charcoal, a mass containing sodium sulphide is obtained which blackens a moistened silver surface (p. 122, § 2). The fine powder is rather soluble in *boiling dilute* HCl. The solution on cooling deposits *lead chloride*, and, after filtering, it gives with barium chloride a precipitate of barium sulphate.	Give water in the closed tube. The HCl solution gives a blue color when ammonia is added in excess.	Linarite.	$[(Pb,Cu)OH]_2SO_4$.	Azure-blue.	Vitreous.	C. Pinac., *per.* F. Conchoidal.	2.5	5.45	1.5	Monocl.
		Caledonite.	$[(Pb,Cu)OH]_2SO_4$?	Bluish-green.	Resinous.	C. Basal, *per.*	2.5–3	6.40	1.5	Orthorh.
	B. B. gives a strong soda flame.	Caracolite.	$Pb(OH)Cl.Na_2SO_4$	Colorless or white.	Vitreous.	F. Uneven.	4.5		1.5–2	Orthorh.
	Gives much water in the closed tube. Reacts for ferric iron, and a phosphate or arsenate. ☞ Compare *Lossenite*, beyond.	Beudantite.	Uncertain. Fe''', Pb, Cu, SO_4, $(P,As)O_4$.	Olive-green, brown, black.	Resinous.	C. Basal.	3.5–4.5	4–4.30	3.5	Hex. Rh.
	Give none of the above reactions.	**ANGLESITE.**	$PbSO_4$.	Colorless or white.	Adamantine.	C. Basal. F. Conchoidal.	3	6.35	2.5	Orthorh. U. cryst.
		Lanarkite.	$(Pb_2O)SO_4$.	Pale-yellow or white.	Pearly, adamantine	C. Basal, *per.*	2–2.5	6.40	2	Monocl.
Phosphates.—A few drops of the *dilute* HNO_3 solution, when added to ammonium molybdate, give a yellow precipitate (p. 102, § 1). ☞ Compare the *Arsenates*, below.	Fusible B. B. alone on charcoal to a globule which, on slow cooling, generally becomes distinctly crystalline. B. B. in a closed tube gives a slight sublimate of lead chloride.	**PYROMORPHITE.**	$Pb_4(PbCl)(PO_4)_3 = 3Pb_3(PO_4)_2.PbCl_2$.	Green, brown, yellow, gray, white.	Resinous.	F. Uneven.	3.5–4	6.5–7.1	2.	Hexag. Cl.8.p.219 U. prismatic.
	Imparts a green color to the salt of phosphorus bead in O. F. (*chromium*).	Vauquelinite. (Laxmannite.)	$(Pb,Cu)_3(PO_4)_2.2(Pb,Cu)CrO_4$.	Green and brown.	Resinous.	F. Uneven.	2.5–3	5.8–6.1	2 ?	Monocl.
	Gives much water in the closed tube.	Plumbogummite.	Uncertain. (PO_4), Pb, Al, H_2O.	Yellow, brown and green.	Gum-like.	F. Uneven.	4–5	4–4.9	2 ?	Hexag. Globular.
Arsenates.—A fragment of the mineral when placed in a closed tube with a few splinters of charcoal, and heated intensely B. B., gives a deposit of arsenic (p. 51, § 1, *a*).	The dilute HNO_3 solution gives with silver nitrate a precipitate of silver chloride. ☞ Compare *Endlichite*, below.	**Mimetite.**	$Pb_4(PbCl)(AsO_4)_3 = 3Pb_3(AsO_4)_2.PbCl_2$.	Colorless, yellow, orange, brown.	Resinous.	F. Uneven.	3.5	7–7.2	1.5	Hexag. Cl.8.p.219 U. prism.
		Ecdemite.	$Pb_4As_2O_7.2PbCl_2$?	Yellow to green.	Greasy.	C. Basal.	2.5–3	6.9–7.1	1.5 ?	Orthorh.
	Fuse B. B. to a magnetic mass. Lossenite reacts for a sulphate (p. 122, § 1).	Carminite.	$Pb_3Fe'''_{10}(AsO_4)_{12}$?	Carmine-red.	Vitreous.	C. Prismatic.	2.5	4.10	2–3 ?	Orthorh.
		Lossenite.	$(Fe'''.OH)_9(AsO_4)_6.PbSO_4.12H_2O$.	Yellow to brownish-red.	Resinous.	F. Uneven.	3–4		2–2.5	Orthorh.
	The HNO_3 solution is rendered blue by ammonia (*copper*).	Bayldonite.	$(Pb,Cu)_3(AsO_4)_2.(Pb,Cu)(OH)_2.H_2O$.	Grass- to blackish-green.	Resinous.	F. Uneven.	4.5	5.35	2–3 ?	Mammill.
	Imparts a bluish-green color to the Na_2CO_3 bead in O. F. (*manganese*).	Caryinite.	$R_3As_2O_8$. R = Mn, Ca, Mg & Pb.	Brown.	Resinous.	C. Pinacoidal. F. Uneven.	3–3.5	4.30	2.5	Massive.
Vanadates.—Impart to the salt of phosphorus bead in O. F. a yellow to deep amber color which in R. F. is changed to green.	The dilute HNO_3 solution gives with silver nitrate a precipitate of silver chloride. Endlichite is a variety containing a little arsenic.	**Vanadinite.** (Endlichite.)	$Pb_4(PbCl)(VO_4)_3 = 3Pb_3(VO_4)_2.PbCl_2$. As iso. w. V.	Ruby-red, brown and yellow.	Resinous.	F. Uneven.	3	6.9–7.1	1.5	Hexag. Page 190. U. prism.
	The HNO_3 solution is rendered blue by addition of ammonia (*copper*). Cuprodescloizite is a variety of the following mineral.	Psittacinite.	Uncertain. (VO_4), Pb, Cu, H_2O	Green.					2 ?	Mammill. earthy.
		Cuprodescloizite.	$R(R.OH)VO_4$. R = Pb, Zn & Cu.	Brown to greenish-black.	Resinous, greasy.	F. Uneven.	3.5	6.20	1.5	Orthor. Radiated.
	Gives water in the closed tube. Reacts for zinc.	**Descloizite.**	$Pb(Pb.OH)VO_4$. Zn iso. w. Pb.	Brownish-black, brown and red.	Resinous, greasy.	F. Uneven.	3.5	6–6.10	1.5	Orthorh. U. cryst.
	Gives water in the closed tube. Contains neither zinc nor copper.	Brackebuschite.	Uncertain. (VO_4), Pb, Fe, Mn, H_2O.	Dark brown.					1.5 ?	Monocl.

DIVISION 2.—Lead Compounds.—Continued on next page.

(Page 261.)

II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 2.—**Lead Compounds**, continued.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

Part I.—Give a metallic globule when fused with sodium carbonate on charcoal.

Division 2.—**Lead Compounds.**—Continued.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Chromates.—Impart to the salt of phosphorus bead in O. F. a green color.	Streak orange-yellow.	**Crocoite.**	$PbCrO_4$.	Bright-red.	Adamantine.	F. Uneven.	2.5–3	5.9–6.1	1.5	Monocl. U. cryst.
	Streak brick-red.	Phœnicochroite.	$2PbCrO_4.PbO$.	Red.	Resinous.	C. Pinacoidal, *perfect.*	3–3.5	5.75?	1.5	Orthorh. U. mass.
Molybdate.—Gives the test for molybdenum when treated as directed on p. 96, § 4.	With salt of phosphorus the bead in R. F. is green, but in O. F. it is yellowish-green when hot, almost colorless when cold.	**Wulfenite.**	$PbMoO_4$.	Yellow, orange, red, gray, white.	Vitreous to adamantine.	F. Uneven.	4.5–5	6.05	2	Tetrag. Cl. 23, p. 219. U. tabular
Tungstate.—Decomposed by boiling with HCl, leaving a yellow residue of tungstic oxide.	If the tungstic oxide (after decanting off the HCl) is treated first with ammonia, then with HCl in excess, and boiled with tin, a fine blue color is obtained (p. 128, § 1).	Stolzite.	$PbWO_4$.	Light green, yellow, brown or red.	Resinous.	F. Uneven.	3	7.9–8.1	2.5–3	Tetrag. Cl. 20, p. 219.
		Raspite.	$PbWO_4$.	Wax-brown.	Resinous.	C. Pinacoidal, *perfect.*	2.5–3		2.5–3	Monocl.
Contain *antimony.*—Alone on charcoal in R. F. give a malleable lead globule and coatings of both lead and antimony oxides. Mixed with three volumes of Na_2CO_3 and fused in charcoal in R. F., give a somewhat brittle globule (alloy of lead and antimony) which yields a sublimate of oxide of antimony when roasted in a bent open tube (Fig. 17, p. 19).	In the closed tube give a sublimate of *lead chloride*, which fuses to colorless globules.	Nadorite.	$PbClSbO_2$.	Smoky- to yellowish-brown.	Resinous.	C. Pinacoidal, *perfect.*	3.5–4	7.0	1.5	Orthorh.
		Ochrolite.	$Pb_4Sb_2O_7.PbCl_2$?	Sulphur- to grayish-yellow	Adamantine.				1.5?	Orthorh.
	In the closed tube gives water.	Bindheimite.	Uncertain. Sb_2O_5, PbO and H_2O.	Gray, yellow, brown.	Resinous to dull.	F. Uneven.	4	4.6–5.0	3–4	Amorph.
Contain *chlorine*, but do not give the reactions of the foregoing sections.—Soluble in warm, dilute HNO_3. The solution gives with silver nitrate a precipitate of *silver chloride.*	B. B. give a blue or green flame. The HNO_3 solution is rendered blue by addition of ammonia (*copper*).	Percylite. (Boléite.)	$PbCuCl_2(OH)_2$.	Indigo-blue.	Brilliant.	C. Cubic, *per.*	3	5.08	1	Isometric. Cubic.
		Cumengite.	$PbCuCl_2(OH)_2$.	Indigo-blue.	Brilliant.	C. Pyramidal.	3	4.71	1	Tetrag.
	Give no water in the closed tube, but yield a sublimate of *lead chloride* which fuses to colorless globules. Cotunnite is wholly volatile when heated in the closed tube, while the others leave a residue of easily fusible lead oxide.	Cotunnite.	$PbCl_2$.	Colorless or white.	Adamantine.	F. Uneven.	1–2	5.80	1	Orthorh.
		Penfieldite.	$2PbCl_2.PbO$.	Colorless to white.	Vitreous to greasy.	C. Basal, *per.* F. Uneven.	2.5		1	Hexag. Prismatic.
		Matlockite.	$PbCl_2.PbO$.	Pale yellow to white.	Adamantine, pearly.	C. Basal. F. Uneven.	2.5–3	7.20	1	Tetrag. Tabular.
		Mendipite.	$PbCl_2.2PbO$.	Pale yellow to white.	Pearly to adamantine.	C. Prismatic, *per.* and basal.	2.5–3	7.10	1	Orthorh. Columnar
	Gives sublimates of both water and lead chloride in the closed tube.	Laurionite.	$PbCl(OH)$.	Colorless or white.	Adamantine.	F. Uneven.	3–3.5		1	Orthorh.
Contains *iodine.* — The dilute HNO_3 solution gives with silver nitrate a precipitate of *silver iodide.*	Gives a sublimate of *lead iodide* (dark-red when hot, yellow when cold) and iodine vapors in the closed tube.	Schwartzenbergite.	$Pb(I,Cl)_2.2PbO$.	Honey- to straw-yellow.	Adamantine.		2–2.5	6.2–6.3	1	Hex. Rh.

Division 2.—**Lead Compounds.**—Concluded on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 2.—**Lead Compounds,** concluded.

DIVISION 3.—**Bismuth Compounds.**

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 2.—**Lead Compounds**.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Silicates.—The three first minerals are readily decomposed by HNO_3 and yield gelatinous silica upon evaporation. Melanotekite and Kentrolite are best decomposed by HCl, but contain too little silica to give a good jelly. They leave a residue of silica, however, when the HCl solution is evaporated to dryness and then treated with acid. Hyalotekite is insoluble in acids, but may be tested as directed on p. 110, § 4.	Gives the reaction for sulphur (p. 122, § 2). The only mineral containing the *sulphite* radical.	Roeblingite.	$5H_2CaSiO_4.2(PbOCa)SO_3$.	White.	Dull-white.		2.5–3	3.43	3	Granular.
	Distinguished by differences in physical properties and by the presence of calcium (CaO = 9%) in Ganomalite.	Barysilite.	$Pb_3Si_2O_7$.	White.	Pearly.	C. Basal.	3	6.50	2.5	Hexag. Lamellar.
		Ganomalite.	$Pb_3Si_2O_7.(Ca,Mn)_2SiO_4$.	Colorless to gray.	Resinous to vitreous.	F. Uneven.	3	5.74	3?	Tetrag.
	B. B. in R. F. fuses to a magnetic bead.	Melanotekite.	$(Fe'''_4O_3)Pb_3(SiO_4)_3$	Dark-brown to black.	Sub-metallic.	F. Uneven.	5–5.5	5.85	2–2.5	Orthorh.
	Imparts a reddish-violet color to the borax bead in O. F. (*manganese*). Soluble in HCl with evolution of chlorine.	Kentrolite.	$(Mn_4O_3)Pb_3(SiO_4)_3$. Fe iso. w. Mn.	Black.	Sub-metallic.	F. Uneven.	5–5.5	6.19	2–2.5	Orthorh.
	Reacts for barium (p. 53, § 3, *b*) and boron (p. 56, § 2).	Hyalotekite.	$R_4(F,OH)B(SiO_3)_6$. R = Pb, Ba & Ca.	White to gray.	Vitreous to greasy.	C. Two directions.	5–5.5	3.80	3?	Massive.
Oxides.—Do not give the reactions of the foregoing minerals.	The colors of the different minerals are very characteristic. Plattnerite and Minium give oxygen gas when heated in the closed tube (p. 100, § 1) and leave readily fusible lead oxide (PbO).	Plattnerite.	PbO_2.	Brown-black.	Sub-metallic.	F. Uneven.	5–5.5	8.50	1.5	Tetrag. U. mass.
		Minium.	Pb_3O_4.	Red.	Dull or greasy.		2–3	4.6?	1.5	Pulverulent.
		Massicot.	PbO.	Sulphur- to reddish-yellow.	Dull.		2	8–9.2	1.5	Massive. Scaly.

DIVISION 3.—**Bismuth Compounds.**—*Globules of bismuth* which are brittle and a *yellow coating of bismuth oxide* are easily obtained by fusion B. B. on charcoal with sodium carbonate. The red sublimate obtained by heating on charcoal with a mixture of potassium iodide and sulphur (p. 55, § 2) may be recommended as a very characteristic test for bismuth.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Carbonates.—Dissolve in HCl with evolution of *carbon dioxide* (effervescence).	In the closed tube gives little or no water.	Bismutosphærite.	$(BiO)_2CO_3$.	White or gray.	Dull.	F. Uneven.	3–3.5	7.42	1.5	Botryoid. Massive.
	In the closed tube gives water.	Bismutite.	$(BiO)(Bi.2OH)CO_3$.	White, green, yellow.	Dull.		4–4.5	6.9–7.7	1.5	Amorph. Earthy.
Contains *chlorine.*—The dilute HNO_3 solution gives with silver nitrate a precipitate of *silver chloride.*	In the closed tube gives water.	Daubréeite.	$2Bi_2O_3.BiCl_3.3H_2O$.	Yellowish- to grayish-white.	Dull.		2–2.5	6.45	1.5?	Amorph. Earthy.
Silicates.—Soluble in HCl, and yield gelatinous silica upon evaporation.	Distinguished by differences in crystallization.	Eulytite.	$Bi_4(SiO_4)_3$.	Hair-brown, yellow, colorless.	Resinous to adamantine.	F. Uneven.	4.5	6.1	2	Isom. Tet. U. cryst.
		Agricolite.	$Bi_4(SiO_4)_3$.	Yellow, hair-brown.	Adamantine.		3?	6?	2	Monocl. Globular.
Vanadate.—Imparts to the salt of phosphorus bead in O. F. a yellow and in R. F. a green color.	Soluble in HCl.	Pucherite.	$BiVO_4$.	Reddish-brown.	Vitreous to adamantine.	C. Basal, *per.* F. Uneven.	4	6.25	2	Orthorh. U. cryst.
Arsenates.—A fragment of the mineral when placed in a closed tube with a few splinters of charcoal, and heated intensely B. B., gives a deposit of arsenic (p. 51, § 1, *a*). ☞ Compare *Mixite* (p. 264).	Imparts to the salt of phosphorus bead in R. F. a green color (*uranium*).	Walpurgite.	$Bi_{10}(UO_2)_3(OH)_{24}(AsO_4)_4$.	Wax-yellow.	Adamantine to greasy.	C. Pinacoidal.	3.5	5.76	1.5	Triclinic.
	React only for arsenic, bismuth and water. Atelesite decrepitates.	Atelestite.	$(Bi.2OH)(BiO)_2AsO_4$.	Sulphur-yellow.	Adamantine.	F. Uneven.	3–4	6.40	1.5	Monocl.
		Rhagite.	$3Bi(OH)_3.2BiAsO_4$?	Yellowish-green to wax-yellow.	Resinous to adamantine.	F. Uneven.	5	6.80	1.5?	Mammill.
Tellurate.—When mixed with Na_2CO_3 and charcoal powder and heated in a closed tube, sodium telluride is formed, which, when treated with water, yields a reddish-violet solution (p. 124).		Montanite.	$(Bi.2OH)_2TeO_4$.	Yellow, green and white.	Dull.				1.5?	Massive. Earthy.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 4.—**Antimony Compounds.**

DIVISION 5.—**Copper Compounds,** in part.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 4.—**Antimony Compounds.**—*Globules of antimony* which are brittle, and a *white coating of antimony oxide*, are obtained by fusing B. B. on charcoal with sodium carbonate.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Fused with Na_2CO_3, then treated with HCl and boiled with tin, the solution assumes a violet color (*titanium*, p. 127, § 2).	Mauzeliite gives a reaction for lead. ☞ Compare *Derbylite* (p. 255).	Mauzeliite.	$(Ca,Pb,Na_2)_4TiSb_4O_{16}$.	Brown.			6–6.5	5.10		Isometric.
		Lewisite.	$(Ca,Fe)_5Ti_2Sb_6O_{24}$.	Honey-yellow to brown.	Resinous.	C. Octahedral.	5.5	4.95	3–4?	Isometric.
Gives no reaction for titanium.	B. B. fuses to a magnetic mass.	Tripuhyite.	$Fe''_2Sb_2O_7$.	Greenish-yellow.	Resinous.			5.82	4–5?	?
	B. B. fuses to a dark non-magnetic slag.	Romeite.	$CaSb_2O_4$.	Honey-yellow.		F. Uneven.	5.5	4.70		Tetrag.

DIVISION 5.—**Copper Compounds.**—A *globule of copper* may be obtained by mixing a small quantity of the mineral with sodium carbonate and fusing on charcoal in a reducing flame. In some cases (when iron is present) it is advisable to use a little borax with the sodium carbonate in order to make the copper unite to a globule (p. 73, § 2). When arsenic is present it may happen that a somewhat brittle globule containing arsenide of copper will result. Moistened with hydrochloric acid and heated B. B. the minerals color the flame azure-blue or green (p. 72, § 1). When dissolved in acids the solutions are rendered deep-blue by addition of ammonia in excess.

N.B.—Nearly all of the minerals containing copper which have non-metallic luster will be found in this division. Most of them have either a green or a blue color.

Characterized by a deep-red color. Note the reaction for *cuprous oxide*.	An ivory-spoonful of the powdered mineral dissolved in 1 c.c. of boiling HCl, then treated with cold water, will give a white precipitate of *cuprous chloride* (p. 74, § 5).	**CUPRITE.** (Ruby Copper.)	Cu_2O.	Intense ruby-red.	Adamantine.	F. Conchoidal or uneven.	3.5–4	6.00	3	Isometric. Cl. 4, p. 219 Figs. 95 to 104.
Carbonates. — Soluble in HCl with evolution of *carbon dioxide* (effervescence).	Give water in the closed tube. Readily distinguished by their color.	**MALACHITE.**	$(Cu.OH)_2CO_3 = CuCO_3.Cu(OH)_2$.	Bright-green.	Vitreous.	C. Basal, *per.* F. Uneven.	3.5–4	3.9–4.0	3	Monocl. U. mamm.
		AZURITE.	$(Cu.OH)_2Cu(CO_3)_2 = 2CuCO_3.Cu(OH)_2$	Intense azure-blue.	Vitreous.	F. Conchoidal or uneven	3.5–4	3.77	3	Monocl. U. cryst.
Contain *chlorine.*—Impart to the blowpipe flame an azure-blue color without previous moistening with HCl. Silver nitrate gives a precipitate of *silver chloride* when added to the dilute HNO_3 solution.	The HCl solution gives a slight precipitate with barium chloride (*sulphate*). Spangolite exhibits pyro-electricity (p. 231).	Spangolite.	$(AlCl)SO_4.6Cu(OH)_2.3H_2O$	Dark-green.	Vitreous.	C. Basal, *per.*	2–3	3.14	3	Hexag. Cl. 13, p. 219.
		Connellite.	$Cu_{15}(Cl,OH)_4SO_{16}.15H_2O$.	Beautiful-blue	Vitreous.	F. Uneven.	3.	3.36	2.5	Hexag. Prismatic
	Gives no water in the closed tube.	Nantokite.	$CuCl$.	Colorless or white.	Adamantine.	F. Conchoidal.	2–2.5	3.93	1.5	Isometric.
	Give acid water in the closed tube.	Atacamite.	$Cu_2Cl(OH)_3 = CuCl_2.3Cu(OH)_2$.	Deep emerald-green.	Adamantine, vitreous.	C. Pinac., *per.* F. Conchoidal.	3–3.5	3.75	3–4	Orthorh. U. cryst.
		Footeite.	$8Cu(OH)_2.CuCl_2.4H_2O$?	Deep-blue.						Monocl.
Contains *iodine.* — Colors the blowpipe flame intense green.	Heated with potassium bisulphate in a closed tube gives vapors of iodine.	Marshite.	CuI.	Reddish-brown.	Resinous.	F. Uneven.			1.5?	Isom. Tet.

DIVISION 5.—**Copper Compounds.**—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 5.—**Copper Compounds,** continued.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 5.—**Copper Compounds.**—Continued.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Sulphates.—The dilute HCl solution gives with barium chloride a precipitate of *barium sulphate.* Give the sulphur reaction on moistened silver after previous fusion with Na_2CO_3 and charcoal powder (p. 122, § 2).	Wholly soluble in water.	Gives much water in the closed tube. Characterized by its color.	**Chalcanthite.** (Blue Vitriol.)	$CuSO_4.5H_2O$.	Azure-blue (rather deep).	Vitreous.	F. Conchoidal.	2.5	2.2	3	Triclinic, Page 217.
		Gives little or no water in the closed tube.	**Hydrocyanite.**	$CuSO_4$.	Pale green, brownish-yellow.					3	Orthorh.
		Yields a magnetic mass after heating B. B. on charcoal.	**Pisanite.**	$(Fe,Cu)SO_4.7H_2O$.	Bright-blue.	Vitreous.	C. Basal.	2.5		3–4	Monocl.
		Imparts a yellow color to the blowpipe flame (*sodium*).	**Kröhnkite.**	$CuSO_4.Na_2SO_4.2H_2O$.	Azure-blue.	Vitreous.	C. Prismatic. F. Conchoidal.	2.5	1.98	1	Monocl.
		Reacts for potassium (p. 106, § 3).	**Cyanochroite.**	$CuSO_4.K_2SO_4.6H_2O$.	Blue.	Vitreous.				1?	Monocl.
	Insoluble or only partly soluble in water.	Gives little or no water in the closed tube.	**Dolerophanite.**	$(Cu_2O)SO_4$.	Brown.					3	Monocl.
		The HCl solution gives with ammonia a precipitate of aluminium hydroxide (seen with difficulty unless filtered).	**Cyanotrichite.** (Lettsomite.)	$Cu_4Al_2SO_{10}.8H_2O$.	Clear-blue.	Pearly.			2.7	3	Orthorh. U. capill.
		Gives the reaction for an arsenate (p. 51, § *c*).	**Lindackerite.**	$(Cu.OH)_4Cu_2Ni_3(SO_4)(AsO_4)_4.5H_2O$.	Verdigris- to apple-green.	Vitreous.		2–2.5	2–2.5	2–3?	Orthorh.
		Distinguished by differences in crystallization and color. Herrengrundite reacts for calcium.	**Brochantite.**	$CuSO_4.3Cu(OH)_2$.	Deep emerald-green.	Vitreous.	C. Pinac., *per.* F. Uneven.	3.5–4	3.9	3.5	Orthorh. U. cryst.
			Langite.	$CuSO_4.3Cu(OH)_2.H_2O$.	Blue to greenish-blue.	Vitreous.	C. Pinacoidal.	2.5–3	3.50	3.5	Orthorh.
			Herrengrundite.	$2(Cu.OH)_2SO_4.Cu(OH)_2.3H_2O$. Ca iso. w. Cu.	Emerald-green.	Vitreous.	C. Basal, *per.*	2.5	3.1	3.5	Monocl.
Nitrate.—Heated in the closed tube gives red vapors of nitrogen dioxide, NO_2.		Gives strongly acid water in the closed tube.	**Gerhardtite.**	$Cu(NO_3)_2.3Cu(OH)_2$	Deep emerald-green.	Vitreous.	C. Basal, *per.*	2	3.42	3	Orthorh.
Arsenates. — When heated intensely B. B. in a closed tube with a few splinters of charcoal, most of these minerals (all of the easily fusible ones) are reduced and an *arsenical mirror* is formed (p. 51, § *a*). When the foregoing treatment does not yield a satisfactory result, the method given on p. 51, § *c*, may be used.		Fuses B. B. on charcoal to a magnetic mass. Reacts for *ferric iron* (p. 85, § 4).	**Chenevixite.**	$Cu_2(FeO)_2(AsO_4)_2.3H_2O$.	Dark-green to olive-green.	Dull.	F. Uneven.	3.5–4.5	3.93	2.5	Massive. Compact.
		A drop of dilute H_2SO_4 produces in the concentrated HCl solution a precipitate of *calcium sulphate* (p. 59, § 3).	**Conichalcite.**	$(Cu,Ca)(Cu.OH)(As,P)O_4.\frac{1}{4}H_2O$.	Emerald-green	Vitreous.	F. Splintery.	4.5	4.12	2.5–3	Massive. Mammill.
			Tyrolite.	$(Cu,Ca)(Cu.OH)_4(AsO_4)_2.7H_2O$.	Pale apple-green.	Pearly and vitreous.	C. Basal, *per.*, foliated.	1–1.5	3.05	2–2.5	Orthorh.
		Gives a coating of oxide of zinc when fused on charcoal in R. F. with a little Na_2CO_3.	**Veszelyite.**	$7(Cu,Zn)O.(As,P)_2O_5.9H_2O$?	Greenish-blue.	Vitreous ?		3.5–4	3.53		Triclinic?
		Heated on charcoal with potassium iodide and sulphur gives a red sublimate (p. 55, § 2).	**Mixite.**	$Cu_2(Cu.OH)_8Bi(AsO_4)_5.7H_2O$?	Pale-green.	Vitreous.		3–4	3.79	2	Capillary.
		Imparts to the salt of phosphorus bead in R. F. a green color (*uranium*).	**Zeunerite.**	$Cu(UO_2)_2(AsO_4)_2.8H_2O$.	Emerald-green.	Pearly and vitreous.	C. Basal, *per.* F. Uneven.	2–2.5	3.2	3	Tetrag. U. tabul.
		Barium chloride produces in the dilute HCl solution a precipitate of *barium sulphate.*	**Lindackerite.**	$(Cu.OH)_4Cu_2Ni_3(SO_4)(AsO_4)_4.5H_2O$	Verdigris- to apple-green.	Vitreous.		2–2.5	2–2.5	2–3?	Orthorh.
		B. B. cracks and then fuses. Reacts for aluminium (p. 42, § 2).	**Liroconite.**	$(Cu.OH)_9[Al_4(OH)_6](AsO_4)_5.20H_2O$?	Sky-blue, at times greenish.	Vitreous.	F. Uneven.	2–2.5	2.9	3–3.5	Monocl.
☞ *Arsenates* concluded on next page.		Has a tendency to exfoliate and fall to pieces when heated B. B.	**Clinoclasite.**	$(Cu.OH)_3AsO_4$.	Dark-green or bluish-green.	Pearly and vitreous.	C. Basal, *per.*	2.5–3	4.36	2–2.5	Monocl.

DIVISION 5.—**Copper Compounds.**—Concluded on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 5.—**Copper Compounds,** concluded.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART I.—Give a metallic globule when fused with sodium carbonate on charcoal.

DIVISION 5.—Copper Compounds.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Arsenates, concluded. — When heated intensely B. B. in a closed tube with a few splinters of charcoal, most of these minerals (all of the easily fusible ones) are reduced and an *arsenical mirror* is formed (p. 51, § *a*). When the foregoing treatment does not yield a satisfactory result, the method given on p. 51, § *c*, may be used.	Decrepitates violently when heated in the closed tube.	Chalcophyllite.	$(Cu.OH)_3AsO_4.Cu(OH)_2.3\frac{1}{2}H_2O.$	Grass-green.	Pearly and vitreous.	C. Basal, *per*.	2	2.4–2.6	2–2.5	Hex. Rh. U. tabul.
	After fusing B. B. in the forceps the globule appears distinctly crystalline. Euchroite contains water of crystallization, and loses it readily in a closed tube like gypsum (p. 82, § 1, *b*). Olivinite gives a little water at a faint red heat.	**Olivenite.**	$Cu(Cu.OH)AsO_4.$	Blackish- and olive-green to brown.	Vitreous to adamantine.	F. Uneven.	3	4.4	2–2.5	Orthorh. U. prism.
		Euchroite.	$Cu(Cu.OH)AsO_4.3H_2O.$	Emerald-green	Vitreous.	F. Uneven.	3.5–4	3.39	2–2.5	Orthorh.
	As these minerals have not been observed in distinct crystals, a quantitative determination of some of their constituents may be necessary for identification. Erinite contains 5 per cent of water, Cornwallite 8, Leucochalcite 10, and Trichalcite 16.	Erinite.	$Cu(Cu.OH)_4(AsO_4)_2$	Emerald-green	Dull to resinous.	F. Uneven.	4.5–5	4.04	2–2.5	Mammill.
		Cornwallite.	$Cu(Cu.OH)_4(AsO_4)_2.3H_2O.$	Emerald-green		F. Uneven.	4.5	4.16	2–2.5	Massive.
		Leucochalcite.	$Cu(Cu.OH)AsO_4.H_2O.$	White to pale-green.	Silky.				2–2.5	Capillary.
		Trichalcite.	$Cu_3(AsO_4)_2.5H_2O.$	Verdigris-green.	Silky.		2.5		2–2.5	Column. Radiated.
Phosphates.—A little of the HNO_3 solution when added to ammonium molybdate gives a yellow precipitate (p. 102, § 1).	Fuses B. B. on charcoal to a magnetic mass. Reacts for *ferric iron* (p. 85, § 4).	Chalcosiderite.	$Cu(Fe,Al)_2FeO)_4(PO_4)_4.8H_2O.$	Light- to dark-green.	Vitreous.	C. Pinac., *per*.	4.5	3.1	4–4.5	Triclinic.
	Imparts to the salt of phosphorus bead in R. F. a green color (*uranium*).	**Torbernite.** (Uran-mica.)	$Cu(UO_2)_2(PO_4)_2.8H_2O.$	Emerald- to apple-green.	Pearly and vitreous.	C. Basal, *per*., foliated.	2–2.5	3.4–3.6	3	Tetrag. U. tabul.
	Distinguished by differences in crystallization and physical properties.	**Libethenite.**	$Cu(Cu.OH)PO_4.$	Dark-green to olive-green.	Resinous.	F. Uneven.	4	3.6–3.8	2–2.5	Orthorh.
		Dihydrite.	$Cu(Cu.OH)_4(PO_4)_2.$	Dark emerald-green.	Vitreous.	F. Uneven.	4.5–5	4–4.4	2–2.5	Monocl.? Triclinic?
		Pseudomalachite.	$(Cu.OH)_3PO_4.$	Emerald- to dark-green.	Vitreous.	F. Uneven.	4.5–5	4.1–4.4	2–2.5	Massive. U. botryo.
		Tagilite.	$Cu(Cu.OH)PO_4.H_2O.$	Emerald-green	Vitreous.	F. Uneven.	3–4	4.07	2–2.5	Monocl. U. fibrous.
Vanadates.—Give the reaction for vanadium when treated as directed on p. 130, § 2. Calciovolborthite contains 5 and Volborthite 34 per cent of water.		Calciovolborthite.	$(Cu,Ca)(Cu.OH)VO_4.$	Green to gray.		C. Pinacoidal.	3.5	3.5–3.86	1.5–2	Tabular. Granular.
		Volborthite.	$(R.OH)_3VO_4.6H_2O.$ R = Cu, Ca, Mg & Ba.			C. Pinac., *per*.	3–3.5	3.55	1.5?	Tabular.
Tungstate.—Decomposed by boiling HCl, leaving a yellow residue of *tungstic oxide* (p. 128, § 1).		Cuprotungstite.	$CuWO_4.$ Ca iso. w. Cu.	Pistachio- to olive-green.	Vitreous.	C. Pinacoidal.	4.5–5		3?	Granular.
Selenite.—When heated in a closed tube, a little water and a less volatile, liquid sublimate of *selenious acid* are obtained. Break off the end of the tube and test the volatile sublimate for the flame coloration as directed on p. 107.		Chalcomenite.	$CuSeO_3.2H_2O.$	Beautiful-blue	Vitreous	F. Uneven.	2.5–3	3.76	1.5	Monocl.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

PART II.—Become magnetic after heating before the blowpipe in the reducing flame.

DIVISION 1.—Soluble in hydrochloric or nitric acid without a perceptible residue and without yielding gelatinous silica upon evaporation.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

Part II.—Become magnetic after heating before the blowpipe in the reducing flame.—*Iron, Cobalt and Nickel Compounds.*

Division 1.—Soluble in hydrochloric or nitric acid without a perceptible residue and without yielding gelatinous silica upon evaporation. For details concerning the method of making this test, see Part III, Division 2, p. 275.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Oxides and hydroxides of iron.—Difficultly fusible. Become strongly magnetic after heating B. B. in R. F. Hematite is anhydrous, the others give water in the closed tube.		Streak brownish-red (Indian-red, red-ocher). ☞ Compare *Turgite* and *Hematite* (p. 253).	**HEMATITE.** (Earthy, non-crystalline.)	Fe_2O_3.	Indian-red.	Dull.	F. Splintery.	5-5.5	4.2–5.0	5–5.5	Earthy. Reniform.
		Streak yellowish-brown (yellow-ocher). Göthite is generally found in distinct crystals, while the others are not.	**GOETHITE.**	$FeO(OH) = Fe_2O_3.H_2O$.	Dark- to yellowish-brown.	Adamantine to dull.	C. Pinac., *per.* F. Splintery.	5-5.5	4.37	5–5.5	Orthorh. U. prism.
			LIMONITE. (Brown Hematite.)	$Fe_4O_3(OH)_6 = 2Fe_2O_3.3H_2O$.	Dark- to yellowish-brown.	Silky or dull.	F. Splintery.	5-5.5	3.6–4.0	5–5.5	Mammill. Stalactitic
			Xanthosiderite.	$Fe_2O(OH)_4 = Fe_2O_3.2H_2O$.	Ocher-yellow.	Silky or dull.		2.5		5–5.5	Capillary. Earthy.
Carbonate.—Soluble in hot HCl with effervescence.		In the closed tube becomes black and magnetic.	**SIDERITE.** (Spathic Iron.)	$FeCO_3$. Mg, Mn, & Ca iso.w.Fe.	Light- to dark-brown.	Vitreous to pearly.	C. Rhombohedral. *per.*	3.5–4	3.8	4.5–5	Hex. Rh. U. cryst.
Sulphates.—**Barium chloride when added** to the dilute HCl solution gives a precipitate of *barium sulphate* (p. 122, § 1). ☞ Concluded on next page. When heated in the closed tube give acid water, and, generally, the odor of sulphur dioxide is perceptible at the end of the tube. The tests for ferrous iron with potassium ferricyanide, and for ferric iron with potassium ferrocyanide, are made in dilute HCl solutions as directed on p. 85, § 4.	React for *ferrous iron*, but not for ferric.	Wholly soluble in cold water.	**Melanterite.** (Copperas.)	$FeSO_4.7H_2O$.	Apple-green.	Vitreous.	C. Basal, *per.*	2	1.9	1. 4.5–5	Monocl.
			Halotrichite.	$FeAl_2(SO_4)_4.24H_2O$	Yellowish-white.	Silky.				4.5–5	Monocl.? Triclinic?
	React for both *ferrous and ferric iron.*	Wholly soluble in cold water.	Römerite.	$Fe''Fe'''_2(SO_4)_4.12H_2O$.	Light- to dark-brown.	Vitreous.	C. Pinac., *per.*	3–3.5	2.15	4.5–5	Triclinic.
		Gives with the salt of phosphorus bead a chromium reaction.	Knoxvillite.	$(Fe,Mg)[(Fe,Cr,Al)OH]_7(SO_4)_8.5H_2O$?	Greenish-yellow.		C. Basal, *per.*			4.5–5?	Orthorh.
		Partly soluble in water, leaving generally a yellowish, ocher-like residue.	Botryogen.	$(Mg,Fe)(Fe.OH)(SO_4)_2.7H_2O$.	Hyacinth-red.	Vitreous.	C. Prismatic.	2–2.5	2–2.15	4.5–5	Monocl. U. botryoidal.
			Voltaite.	$Fe''_3(Fe.OH)_2(Fe,Al)_4(SO_4)_{10}.14H_2O$? Mg, K_2, Na_2 iso. w. Fe.	Oil-green to greenish-black	Resinous.	F. Uneven.	3	2.79	1?	Isometric?
			Metavoltaite.	$(K_2,Na_2,Fe)''_5Fe'''_2(Fe'''.OH)_4(SO_4)_{12}.16H_2O$?	Yellow.			2.5	2.53	4.5–5	Hexag. Scales.
	React for *ferric iron*, but not for ferrous. Wholly soluble in cold water.	Imparts a yellow color to the blowpipe flame (*sodium*).	Ferronatrite.	$Na_3Fe(SO_4)_3.3H_2O$.	Pale greenish-white.	Vitreous.	C. Prismatic, *perfect.*	2	2.55	1.5	Hex. Rh. U. radiat.
		Contain no other base than iron.	**Coquimbite.**	$Fe_2(SO_4)_3.9H_2O$.	White, green, amethystine.	Vitreous.	F. Uneven.	2–2.5	2.1	4.5–5	Hex. Rh. U. cryst.
			Quenstedtite.	$Fe_2(SO_4)_3.10H_2O$.	Reddish-violet	Vitreous.	C. Pinacoidal, *perfect.*	2.5	2.11	4.5–5	Monocl.
			Ihleite.	$Fe_2(SO_4)_3.12H_2O$.	Orange-yellow				1.8	4.5–5	Botryoidal.
	React for *ferric iron*, but not for ferrous. Insoluble, or only partially soluble, in cold water.—Cont'd	Imparts an intense yellow color to the blowpipe flame (*sodium*).	Sideronatrite.	$Na_2(Fe.OH)(SO_4)_2.2H_2O$.	Orange to straw-yellow.	Silky.	C. Pinacoidal.	2–2.5	2.35	2	Orthorh. Fibrous.
		Does not give water in the closed tube at low temperature. Reacts for potassium (p. 105, § 1).	**Jarosite.**	$K(Fe.2OH)_3(SO_4)_2$. Na iso. w. K.	Ocher-yellow to clove-brown.	Vitreous.	C. Basal.	2.5–3.5	3.2	4.5	Hex. Rh. U. cryst.
		With ammonium molybdate gives the reaction for a phosphate (p. 102, § 1).	Diadochite.	$2(Fe.OH)SO_4.2FePO_4.H_2O$.	Yellow or yellowish-brown.	Resinous.	F. Conchoidal.	3	2.03	3?	Monocl.

Division 1.—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART II.—Become magnetic after heating before the blowpipe in the reducing flame.

DIVISION 1, continued.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART II.—Become magnetic after heating before the blowpipe in the reducing flame.—*Iron, Cobalt and Nickel Compounds.*

DIVISION 1.—Continued.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Sulphates, concluded. — Barium chloride when added to the dilute HCl solution gives a precipitate of *barium sulphate* (p. 122, §1). When heated in the closed tube give acid water, and, generally, the odor of sulphur dioxide is perceptible at the end of the tube. React for *ferric iron,* but not for ferrous, when tested as directed on p. 85, § 4. Insoluble, or only partially soluble, in cold water.	Yield an arsenical mirror when placed in a closed tube with a fragment of charcoal, and heated intensely before the blowpipe (p. 51, § *a*).	Pitticite.	Uncertain. $Fe,(AsO_4),(SO_4), H_2O$.	Yellowish- to reddish-brown.	Vitreous, greasy.		2–3	2.2–2.5	2?	Massive. Reniform.
		Lossenite.	$(Fe.OH)_9(AsO_4)_6.PbSO_4.12H_2O$.	Yellow to brownish-red.	Resinous.	F. Uneven.	3–4		2–2.5	Orthorh.
	Except in the case of Cyprusite, which contains a little aluminium, these minerals have only iron as the base. When heated in the closed tube a residue of *ferric oxide* is left, which, when crushed, gives a red mark (red-ocher).	Castanite.	$(Fe.OH)SO_4.3\frac{1}{2}H_2O$.	Chestnut-brown.	Vitreous.		3	2.12	4.5–5	Monocl. Prismatic.
		Copiapite.	$Fe_2(Fe.OH)_2(SO_4)_5.17H_2O$.	Sulphur-yellow.	Pearly.	C. Pinacoidal.	2.5	2.1	4.5–5	Monocl. Tabular.
		Utahite.	$H_6Fe_6S_3O_{22}$.	Orange-yellow.	Silky.				4.5–5	Hex. Rh. Tabular.
		Amarantite.	$(Fe.OH)SO_4.3H_2O$.	Orange- to brownish-red.	Resinous.	C. Two directions, *per.*	2.5	2.28	4.5–5	Triclinic. Prismatic.
		Fibroferrite.	$(Fe.OH)SO_4.4\frac{1}{2}H_2O$.	Pale-yellow.	Silky.		2–2.5	1.85	4.5–5	Monocl.? Fibrous.
		Raimondite.	$Fe_4(OH)_6(SO_4)_3.4H_2O$.	Honey- to ocher-yellow.	Pearly.	C. Basal, *per.*	3–3.5	3.2	4.5–5	Hexag. Tabular.
		Carphosiderite.	$Fe_6(OH)_{10}(SO_4)_4.4H_2O$.	Straw-yellow.	Resinous.	C. Basal.	4–4.5	2.5–2.7	4.5–5	Hex. Rh.? Reniform.
		Glockerite.	$(Fe.2OH)_2SO_4.2Fe(OH)_3.H_2O$?	Brownish-black to ocher-yellow.	Resinous. Earthy.				4.5–5	Massive. Earthy.
		Cyprusite.	$Al(FeO)_7(SO_4)_5.7H_2O$.	Yellow.			2	1.75	4.5–5	Hexag. Tabular.
Arsenates. — When heated intensely B. B. in a closed tube with a fragment of charcoal the arsenate is reduced and an *arsenical mirror* is formed (p. 51, § *a*). Provided the mineral contains much calcium it is best to heat in a closed tube with Na_2CO_3 and charcoal-dust, as directed on p. 51, § *b*.	Give a blue color to the borax bead (*cobalt*). The HCl solution has a rose color. ☞ *Annabergite* below sometimes contains sufficient cobalt to give a blue color to borax.	**Erythrite.** (Cobalt Bloom.)	$Co_3(AsO_4)_2.8H_2O$.	Crimson to peach-red.	Pearly, vitreous.	C. Pinac., *per.*	1.5–2.5	2.95	2.5	Monocl. Prismatic
		Forbesite.	$H(Ni,Co)AsO_4.3\frac{1}{2}H_2O$.	Grayish-white.	Silky.		2.5	3.1		Fibrous.
	Color the borax bead in O. F. violet when hot, brown when cold. The HCl solutions have a green color. Cabrerite is a variety of annabergite containing magnesium.	**Annabergite.** (Nickel Bloom.)	$Ni_3(AsO_4)_2.8H_2O$. Co iso. w. Ni.	Apple-green.	Pearly, vitreous.	C. Pinac., *per.*	1.5–2.5		4	Monocl. Capillary.
		Cabrerite.	$(Ni,Mg)_3(AsO_4)_2.8H_2O$.	Apple-green.	Pearly.	C. Pinac., *per.*	2	2.95–3.1	4–5	Monocl. Prismat.
	Contain *ferric* and no ferrous iron. The HCl solutions have a yellow color, and the addition of ammonia in excess produces a reddish-brown precipitate of basic ferric-arsenate.	**Pharmacosiderite.**	$Fe(Fe.OH)_3(AsO_4)_3.6H_2O$.	Green, yellow, brown, red.	Adamantine.	F. Uneven.	2.5	2.9–3.0	1.5–2	Isom. Tet. U. cryst.
		Scorodite.	$FeAsO_4.2H_2O$.	Pale-green or brown.	Vitreous.	F. Uneven.	3.5–4	3.2	2–2.5	Orthorh. U. cryst.
		Mazapilite.	$[Fe_4(OH)_6]Ca_3(AsO_4)_4.3H_2O$.	Black to brownish-red.	Sub-metallic.	F. Uneven.	4.5	3.57	2–3?	Orthorh. Prismat.
		Arseniosiderite.	$[Fe_4(OH)_6](Ca.OH)_3(AsO_4)_3$.	Yellowish to golden-brown.	Silky.	Fibrous.	1–2	3.5–3.8	3	Fibrous.

DIVISION 1.—Concluded on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART II.—Become magnetic after heating before the blowpipe in the reducing flame.

DIVISION 1, concluded.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART II.—Become magnetic after heating before the blowpipe in the reducing flame.—*Iron, Cobalt and Nickel Compounds.*

DIVISION 1.—Concluded.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Phosphates.—The HNO_3 solution gives with ammonium molybdate a yellow precipitate of ammonium phosphomolybdate (p. 102, § 2). The pale bluish-green flame due to phosphorus may usually be seen when these minerals are heated before the blowpipe. When moistened with H_2SO_4 the color is more decided.	Contain *manganese.*—Impart to the borax bead in O. F. a reddish-violet color. React for *ferrous iron* when the dilute HCl solution is tested with potassium ferrocyanide (p. 85, § 4). ☞ Compare the phosphates of *iron* and *manganese* on p. 276.	Colors the blowpipe flame red (*lithium*). Gives little or no water in the closed tube.	**Triphylite.** See *lithophilite*, p. 276.	$Li(Fe,Mn)PO_4$.	Light blue, green, or gray	Resinous.	C. Basal, *per.*, & Pinacoidal.	4.5–5	3.55	2.5	Orthorh. U. mass.
		Reacts for fluorine (p. 76, § 2). Gives little or no water in the closed tube (OH iso. w. F).	**Triplite.**	$R(RF)PO_4$. R = Fe & Mn, with a little Ca & Mg.	Chestnut- to blackish-brown.	Resinous.	C. Two directions. F. Uneven.	4–5.5	3.6–3.8.	2.5	Monocl. U. mass.
		Gives water in the closed tube. B. B. fuses easily.	Triploidite.	$R(R.OH)PO_4$. R = Fe and Mn.	Yellowish- to reddish-brown	Vitreous, greasy.	C. Pinac., *per.* F. Uneven.	4.5–5	3.70	3	Monocl. Prismat.
		Gives water in the closed tube. B. B. exfoliates and afterwards fuses on the edges.	**Childrenite.** See *eosphorite*, p. 276.	$(Fe,Mn)(Al.2OH)PO_4.H_2O$.	Yellowish-brown to brownish-black.	Vitreous, resinous.	C. Pinacoidal. F. Uneven.	4.5–5	3.20	4	Orthorh. Fig. 309, Page 207.
	React for *ferrous iron* (p. 85, § 4). Contain little or no manganese.	When gently heated in a closed tube, Vivianite whitens, while Ludlamite darkens. Both darken on intense ignition.	**Vivianite.**	$Fe_3(PO_4)_2.8H_2O$.	Blue, bluish-green to colorless.	Pearly to vitreous.	C. Pinac., *per.*	1.5–2	2.6–2.7	2–2.5	Monocl. U. prism.
			Ludlamite.	$Fe_5(Fe.OH)_2(PO_4)_4.8H_2O$.	Pale-green.	Vitreous.	C. Basal, *per.*	3–4	3.12	2–2.5	Monocl. U. tabular
	React for *ferric iron* when the dilute HCl solution is tested with potassium ferrocyanide (p. 85, § 4). All of the minerals in this section give water in the closed tube.	After precipitation of the iron with ammonia and filtering, the solution has a blue color (*copper*).	Chalcosiderite.	$Cu(Fe,Al)_2(FeO)_4(PO_4)_4.8H_2O$.	Light to dark green.	Vitreous.	C. Pinac., *per.*	4.5	3.1	4–4.5	Triclinic.
		If a drop of *dilute* H_2SO_4 is added to the concentrated HCl_4 solution, a precipitate of *calcium sulphate* will be formed.	Borickite.	$Ca(Fe.2OH)_4(PO_4)_2.3H_2O$?	Reddish-brown.	Wax-like.		3.5	2.7	3–4	Massive. Reniform
			Calcioferrite.	$Ca_3(Fe.OH)_3(PO_4)_4.8H_2O$. Al iso.w. Fe & Mg.w. Ca	Sulphur- to greenish-yellow.	Pearly.	C. One direction, *per.*	2.5	2.52		Massive. Foliated.
		Reacts for aluminium, after separating the iron with potassium hydroxide as directed on p. 111.	Barrandite.	$(Al,Fe)PO_4.2H_2O$.	Pale blue, green or yellow.	Vitreous, greasy.	F. Splintery.	4.5	2.57		Spheroidal. Radiated.
		Contain only iron as the base.	Dufrenite.	$Fe_2(OH)_3PO_4$.	Dull olive- to blackish-green	Silky.	F. Splintery.	3.5–4	3.2–3.4	2.5	Orthorh. U. Fibrous
			Beraunite. (Eleonorite.)	$(Fe.OH)_3(PO_4)_2.2\frac{1}{2}H_2O$.	Reddish-brown.	Vitreous.	C. Pinacoidal.		2.95	3	Monocl. U. foliat.
			Phosphosiderite.	$2FePO_4.3\frac{1}{2}H_2O$.	Pale-red or reddish-violet.	Vitreous.	C. Pinac., *per.*	3.75	2.76	2.5–3?	Orthorh.
			Strengite.	$FePO_4.2H_2O$.	Pale-red or reddish-violet.	Vitreous.	C. Pinacoidal. F. Uneven.	3–4	2.87	2.5–3	Orthorh. U. cryst.
			Koninckite.	$FePO_4.3H_2O$.	Yellow.	Vitreous.	F. Splintery.	3.5	2.3	2.5–3	Radiated.
			Cacoxenite.	$Fe_2(OH)_3PO_4.4\frac{1}{2}H_2O$.	Golden-yellow	Silky.		3–4	3.38	2.5–3	Radiated.
Borate.—When heated with the potassium bisulphate and fluorite mixture, momentarily colors the flame green (p. 56, § 1). Reacts for both ferric and ferrous iron.			Ludwigite.	$3MgB_2O_4.Fe''Fe'''_2O_4$.	Blackish-green nearly black.	Dull, silky.	F. Splintery.	5	3.9–4.0	4.5	Orthorh. Fibrous.
Tellurite.—Gives a fusible sublimate of TeO_2 in the open tube. Reacts for ferric iron.			Durdenite.	$Fe_2(TeO_3)_3.4H_2O$.	Greenish-yellow.	Vitreous.		2–2.5			Massive. Mammill.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART II.—Become magnetic after heating before the blowpipe in the reducing flame.

DIVISION 2.—Soluble in hydrochloric or nitric acid, and give gelatinons silica upon evaporation, or decomposed with the separation of silica.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART II.—Become magnetic after heating before the blowpipe in the reducing flame.—*Iron, Cobalt and Nickel Compounds.*

DIVISION 2.—Soluble in hydrochloric or nitric acid and give gelatinous silica upon evaporation, or decomposed with the separation of silica.—For details concerning the method of making this test see Part III, Division 3, p. 278, and Division 4, p. 281.

	General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Give much water in the closed tube.	Gelatinize with hydrochloric acid. ☞ Compare *Allanite* below, which often contains considerable water.	Cronstedtite occurs usually in crystals with triangular cross-section; Thuringite in aggregations of minute scales.	Cronstedtite.	$H_8Fe''_4Fe'''_4Si_3O_{20}$? Mg iso. w. Fe.	Black to brownish-black.	Vitreous.	C. Basal, *per.*	3.5	3.35	4	Hex. Rh. Hemimor.
			Thuringite.	$H_{18}Fe''_8(Al,Fe)_8Si_6O_{41}$?	Olive- to pistachio-green.	Dull.	F. Tough, uneven.	2.5	3.18	4	Compact. Scaly.
	Decomposed by hydrochloric acid with the separation of silica, but without forming a jelly.	Radiated or foliated.	Stilpnomelane. (Chalcodite.)	$H_6(Fe,Mg)_2(Fe,Al)_2Si_5O_{18}$?	Greenish- to yellowish-bronze.	Pearly, bronze-like.	C. One direction.	3	2.75	4.5	Foliated. Velvety.
		Gives a reaction for chlorine when tested as directed on p. 68, § 3.	Pyrosmalite.	$H_7(FeCl)(Fe,Mn)_4(SiO_4)_4$.	Pistachio-green to brown.	Pearly to vitreous.	C. Basal, *per.*	4–4.5	3.1–3.2	3	Hexag. Prismatic.
Give little or no water in the closed tube.	Soluble in HCl with slight evolution of *hydrogen sulphide.*	The *fine powder* when fused with a little Na_2CO_3 on charcoal gives a coating of zinc oxide.	Danalite. (Helvite).	$R_5(R_2S)(SiO_4)_3$. R = Be, Fe, Zn & Mn.	Flesh-red to gray.	Vitreous, resinous.	F. Uneven.	5.5–6	3.43	4.5–5	Isom. Tet.
	Micaceous or foliated.	Gelatinizes with HCl.	**LEPIDOMELANE.**	$(K,H)_2Fe''_2(Fe,Al)_2(SiO_4)_3$?	Black, greenish-black	Adamantine to pearly.	C. Basal, *per.*	3	3–3.2	4.5–5	Monocl.
		Slightly attacked by HCl with separation of silica.	**BIOTITE.** See *the micas*, p. 284.	$(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$.	Green to greenish-black	Splendent, pearly.	C. Basal, *per.*	2.5–3	2.8–3.1	5	Monocl.
		Readily decomposed by HCl with separation of silica. The solution when boiled with tin becomes violet (*titanium*, p. 127, § 2).	Astrophyllite.	$(K,Na,H)_4(Fe,Mn,Mg,Ca)_4Ti(SiO_4)_4$. Zr iso. w. Si.	Bronze- to golden-yellow.	Pearly.	C. Pinac., *per.*	3	3.3–3.4	2.5–3	Orthorh.
	Gelatinize with hydrochloric acid. Give decided reactions for both ferrous and ferric iron (p. 85, § 4).	Fuses quietly.	Ilvaite. (Lievrite.)	$CaFe''_2(Fe'''.OH)(SiO_4)_2$.	Iron-black.	Black.	F. Uneven.	5.5–6	4.05	2.5	Orthorh. U. prism.
		Swells and froths during fusion. The presence of the rare-earth metals may be detected as directed on p. 65.	Allanite.	$R''_2(R'''.OH)R'''_2(SiO_4)_3$. R″ = Ca & Fe. R‴ = Al, Fe, Ce, La, & Di	Brown- to pitch-black.	Gray.	F. uneven to conchoidal.	5.5–6	3.5–4.2	2.5	Monocl. U. mass.
	Gelatinizes imperfectly. Characterized by its isometric crystallization.	Reacts mostly for ferric, although it may also contain some ferrous, iron.	**ANDRADITE.** (Calcium-iron Garnet.)	$Ca_3Fe_2(SiO_4)_3$. Fe, Mn & Mg iso. w. Ca; Al iso. w. Fe.	Wine, greenish yellow, green, brown.	Vitreous, adamantine.	F. Uneven.	7	3.75–3.85	3.5	Isometric. Figs. 97, 105, 106.
	Gelatinize. Give strong reactions for ferrous iron, and little or none for ferric.	Sometimes magnetic before heating, owing to the presence of included particles of magnetite.	Fayalite. (Iron Chrysolite.)	Fe_2SiO_4.	Yellow to dark yellowish-green.	Resinous.	C. Pinacoidal. F. Uneven.	6.5	4.32	4	Orthorh. U. mass.
		Closely related to *Fayalite*, but differing in containing some *magnesium, manganese* or *zinc*, isomorphous with the iron. Test for manganese with the Na_2CO_3 bead, for zinc by fusing with Na_2CO_3 on charcoal, and for magnesium as directed on p. 91, § 1, *b*.	Hortonolite.	$(Fe,Mg,Mn)_2SiO_4$.	Yellow to dark yellowish-green.	Resinous.	C. Pinacoidal. F. Uneven.	6.5	4.03	4.5	Orthorh. U. mass.
			Knebelite.	$(Fe,Mn,Mg)_2SiO_4$.	Gray, brown, green.	Greasy.	C. Pinacoidal. F. Uneven.	6.5	3.9–4.1	3	Orthorh. U. mass
			Rœpperite.	$(Fe,Mn,Mg,Zn)_2SiO_4$.	Yellow to dark yellowish-green.	Greasy.	C. Pinacoidal. F. Uneven.	5.5–6	3.95	4.53	Orthorh. U. mass.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART II.—Become magnetic after heating before the blowpipe in the reducing flame.

DIVISION 3.—Insoluble in, or only slightly acted upon by, acids.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART II.—Become magnetic after heating before the blowpipe in the reducing flame.—*Iron, Cobalt and Nickel Compounds.*

DIVISION 3.—Insoluble in, or only slightly acted upon by, acids.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contains *tungsten.*—Characterized by an exceptionally high specific gravity.	Test for tungsten as directed on p. 129, § 2. Colors the Na_2CO_3 bead in O. F. green (*manganese*).	**Wolframite.** (Manganese variety.)	$(Mn,Fe)WO_4$.	Black.	Sub-metallic.	C. Pinac., *per.* F. Uneven.	5–5.5	7.2–7.5	4	Monocl. U. cryst.
Micaceous.	Easily fusible. Tinges the blowpipe flame red (*lithium*).	Zinnwaldite.	$(K,Li)_3Fe''(AlO)(AlF_2)Al(SiO_3)_5$. OH iso. w. F.	Gray, brown, violet.	Pearly.	C. Basal, *per.*	2.5–3	2.8–3.2	2.5–3	Monocl.
	Difficultly fusible.	**BIOTITE.** See *the micas*, p. 284.	$(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$.	Green to greenish-black	Splendent, pearly.	C. Basal, *per.*	2.5–3	2.8–3.1	5	Monocl.
Distinguished by its isometric crystallization.	Fused garnet is soluble in HCl, and yields a jelly on evaporation.	**ALMANDITE.** (Iron-aluminium Garnet.)	$Fe''_3Al_2(SiO_4)_3$. Mn,Mg & Ca iso. w. Fe; Fe iso. w. Al.	Deep-red to brownish-red.	Vitreous.	F. Uneven.	7–7.5	4–4.15	3	Isometric, Figs. 97, 105, 106.
Quietly and difficultly fusible.	Often has a peculiar metal-like schiller. ☞ Compare *Anthophyllite* (p. 287), which may become magnetic after heating B.B.	**Hypersthene.**	$(Mg,Fe)SiO_3$.	Greenish-black, bronze-brown.	Bronze-like.	C. Pinac., *per.* F. Uneven.	5–6	3.4–3.5	5	Orthorh. U. mass.
Fusible B. B. with intumescence, and impart a decided yellow color to the flame (*sodium*). The perfect prismatic cleavage of these minerals at angles of about 125° and 55° is characteristic. ☞ Compare these members of the Amphibole Group of minerals with those on p. 288.	Contains titanium (p. 127, § 2). The iron is chiefly ferrous (test as directed on p. 86).	Ænigmatite.	Uncertain. $(Fe'',Mn,Ca),(Fe''',Al),Na,(Ti,Si),O$.	Black.	Vitreous.	C. Prismatic. F. Uneven.	6	3.7–3.8	3	Triclinic.
	The iron is chiefly ferrous.	**Arfvedsonite.**	$(Fe,Na_2,Ca)_4(SiO_3)_4$ $Fe_2(Al,Fe)_2Si_2O_{12}$.	Black.	Vitreous.	C. Prism., *per.* F. Uneven.	6	3.45	2.5	Monocl. Prismatic
	Usually has a fibrous structure. The iron is both ferrous and ferric.	Crocidolite.	$NaFe'''(SiO_3)_2$. $(Fe'',Mg,Ca)SiO_3$.	Intense lavender-blue.	Silky.	F. Fibrous.	4	3.2–3.3	3.5	Fibrous.
	Contains both ferrous and ferric iron.	Riebeckite.	$2NaFe'''(SiO_3)_2$. $(Fe,Ca)SiO_3$.	Black.	Vitreous.	C. Prism., *per.*	6 ?	3.43	3?	Monocl.
Fuses quietly B. B., coloring the flame yellow (*sodium*). The fused globule is not very magnetic.	The prismatic faces make nearly a right angle (93°) with one another. The cleavage is not very perfect.	**Acmite.** (Ægirite.)	$NaFe'''(SiO_3)_2$.	Greenish- to brownish-black.	Vitreous.	C. Prismatic. F. Uneven.	6–6.5	3.50	3.5	Monocl. Prismatic.
Fuses quietly, and without marked flame coloration.	Contains both ferrous and ferric iron and much calcium.	Babingtonite.	$(Ca,Fe,Mn)SiO_3$. $Fe_2(SiO_3)_3$.	Greenish-black to black.	Vitreous.	C. One direction, *perfect.* F. Uneven.	5.5–6	3.35–3.40	3–3.5	Triclinic U. cryst.

☞ Compare the dark-green and black varieties of *Pyroxene, Amphibole, Tourmaline and other Silicates* in Division 5, p. 283, which may contain sufficient iron to cause them to become somewhat magnetic when heated before the blowpipe.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives *an alkaline reaction* when placed on turmeric-paper.

Section a.—Easily and Completely Soluble in Water.—In part.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives *an alkaline reaction* when placed on moistened turmeric-paper.

Section a.—Easily and completely soluble in water.

N.B.—The minerals in this section are chiefly salts of the alkali metals, *sodium* and *potassium,* with volatile acids (*hydrochloric, carbonic, sulphuric,* and *nitric*). Most of them have a decided saline taste. Flame tests will generally serve to identify the metals, and it is recommended to make the tests on platinum wire as directed on p. 35. Most minerals will impart some yellow color to the flame (p. 115, § 1), but only those containing sodium as an *essential constituent* give an intense and persistent yellow. The violet flame of potassium, which may not be very evident, has a decided purplish-red color when viewed through rather dark blue glass (p. 105, § 1).

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain *chlorine.*—The aqueous solution, made acid with HNO_3, gives with silver nitrate a precipitate of *silver chloride.*	Combinations of a *chloride* with a *sulphate.*—The aqueous solution made acid with a little HCl gives a precipitate with barium chloride (p. 122, § 1).	Gives a slight effervescence when a fragment is dropped into acid.	Hanksite.	$9Na_2SO_4.2Na_2CO_3.KCl$.	Colorless or white.	Vitreous.	C. Basal. F. Uneven.	3–3.5	2.55	1.5	Hexag. Page 189.
		Does not effervesce. Gives a yellow flame (*sodium*). Reacts for *fluorine* (p. 75, § 1).	Sulphohalite.	$2Na_2SO_4.NaCl.NaF$.	Colorless or white.	Vitreous.	F. Uneven.	3.5	2.50	1	Isometric. Fig. 97.
		Does not effervesce. Gives a violet flame (*potassium*).	Kainite.	$MgSO_4.KCl.3H_2O$.	Colorless or white.	Vitreous.	C. Pinacoidal.	2.5–3	2.05–2.2	1.5–2	Monocl.
	Do not give the foregoing reaction for a sulphate.	Gives an intense yellow flame (*sodium*).	**HALITE.** (Common Salt.)	$NaCl$.	Colorless, white, red, blue.	Vitreous.	C. Cubic, *per.*	2.5	2.13	1.5	Isometric. U. cubic.
		Gives a violet flame (*potassium*). Sylvite is anhydrous. Carnallite contains much water.	**SYLVITE.**	KCl.	Colorless or white.	Vitreous.	C. Cubic, *per.*	2	1.9–2.0	1.5	Isometric. Figs. 98, 99
			Carnallite.	$MgCl_2.KCl.6H_2O$.	Colorless, white, red.	Vitreous.	F. Conchoidal.	1	1.6	1–1.5	Orthorh.
		Give a yellowish-red flame (*calcium*). Deliquesce readily. Tachydrite melts in its water of crystallization.	Hydrophilite.	$CaCl_2$.	Colorless or white.	Vitreous.			2.2	1.5	Isometric.
			Tachydrite.	$2MgCl_2.CaCl_2.12H_2O$.	Wax- to honey-yellow.	Vitreous.		2.5		1	Hex. Rh.
Carbonates. — Effervesce when treated with acids. All minerals in this section give a yellow flame (*sodium*). Their aqueous solutions give an alkaline reaction with turmeric-paper.		Melts in its water of crystallization when gently heated in a closed tube. Water 63 per cent.	**Natron.** (Sal-soda.)	$Na_2CO_3.10H_2O$.	Colorless, gray, white.	Vitreous.	C. Basal. F. Conchoidal.	1–1.5	1.4–1.45	1	Monocl.
		Gives water and carbon dioxide (p. 64, § 2) when *gently heated* (not to fusion) in a closed tube.	**Trona.**	$Na_2CO_3.HNaCO_3.2H_2O$.	Colorless, gray, white.	Vitreous.	C. Pinac., *per.* F. Uneven.	2.5–3	2.1–2.15	1.5	Monocl.
		Gives water (14 per cent) but no carbon dioxide when *gently heated* in a closed tube.	Thermonatrite.	$Na_2CO_3.H_2O$.	White, gray, yellow.	Vitreous.	Somewhat sectile.	1–1.5	1.5–1.6	1.5	Orthorh

DIVISION 1, *Section a.*—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic*.

DIVISION 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives *an alkaline reaction* when placed on turmeric-paper.

Section a.—Easily and Completely Soluble in Water.—Continued.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

Part III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic*.

Division 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives *an alkaline reaction* when placed on moistened turmeric-paper.

Section a.—Easily and completely soluble in water.—Continued.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Sulphates.—The aqueous solutions, made acid with HCl, give with barium chloride a white precipitate of *barium sulphate* (p. 122, § 1), but do not give the reactions of the preceding divisions. The test on silver, after the reduction of the sulphate to a sulphide, may also be applied (p. 122, § 2).	Give no water in the closed tube, and are thus distinguished from the sulphates in the following sections.	Gives a yellow flame (*sodium*), which appears purplish-red when viewed through blue glass (*potassium*).	Aphthitalite.	$(K,Na)_2SO_4$.	Colorless or white.	Vitreous.	C. Prismatic.	3–3.5	2.65	1.5	Hex. Rh.
		Gives a yellow flame. Contains no potassium.	**Thenardite.**	Na_2SO_4.	Colorless, white, brownish.	Vitreous.	C. Basal. F. Uneven.	2–3	2.69	1.5–2	Orthorh.
		Gives a violet flame (*potassium*). Reacts for ammonium (p. 43).	Taylorite.	$K_5(NH_4)(SO_4)_3$.	Yellowish-white.	Vitreous.		2		1.5 ?	Massive.
	Contain *aluminium.*—In a solution made acid with HCl, ammonia gives a precipitate of *aluminium hydroxide* (p 42, § 2).	B. B. swells and gives a yellow flame (*sodium*).	Mendozite.	$NaAl(SO_4)_2.12H_2O$.	White.	Silky-vitreous.	F. Fibrous.	3	1.88	1 ?	Massive. Fibrous.
		B. B. swells and gives a violet flame (*potassium*).	**Kalinite.** (Potash Alum.)	$KAl(SO_4)_2.12H_2O$.	Colorless or white.	Vitreous.	F. Conchoidal.	2–2.5	1.75	1	Isom. Pyr. U. fibrous
	Contain *magnesium.*—In a solution made acid with HCl, ammonia produces no precipitate (provided the solution is not too concentrated), but sodium phosphate, added to the solution made alkaline with ammonia, gives a precipitate of ammonium magnesium phosphate (p. 91, § 1).	Gives the odor of ammonia when heated in a closed tube with lime (p. 43).	Boussingaultite.	$MgSO_4.(NH_4)_2SO_4.6H_2O$.	Colorless or white.	Vitreous.			1.7	1.5–2 ?	Monocl.
		Give no pronounced flame coloration. The alkaline reaction may not be very strong. Have a bitter taste. ☞ Compare *Sulphates*, Division 2, p. 275.	**Epsomite.** (Epsom Salt.)	$MgSO_4.7H_2O$.	Colorless or white.	Vitreous.	C. Pinac., *per.* F. Conchoidal.	2–2.5	1.7	1	Orthorh. Page 207.
			Kieserite.	$MgSO_4.H_2O$.	White, gray, yellow.	Vitreous.	C. Prismatic.	3–3.5	2.56	2–3 ?	Monocl.
		Give a yellow flame coloration (*sodium*).	Löweite.	$MgSO_4.Na_2SO_4.2\frac{1}{2}H_2O$.	White, yellow, red.	Vitreous.	C. Basal. F. Conchoidal	2.5–3	2.38	1.5	Tetrag
			Blödite.	$MgSO_4.Na_2SO_4.4H_2O$.	Colorless or white.	Vitreous.	F. Uneven.	2.5	2.2–2.3	1.5	Monocl.
		Give a violet flame coloration (*potassium*). Langbeinite is anhydrous.	Langbeinite.	$2MgSO_4.K_2SO_4$.	Colorless or white.	Vitreous.	F. Conchoidal.	3–4	2.81	1.5–2	Isometric. Cl. 5, p. 219
			Picromerite.	$MgSO_4.K_2SO_4.6H_2O$.	White.	Vitreous.			2.1–2.2	1.5–2	Monocl.
	Contain *sodium.*—Impart an intense yellow color to the blowpipe or Bunsen-burner flames, but do not give the reactions of the foregoing divisions.	Heated in a bulb tube with potassium bisulphate yields red vapors of NO_2 (*nitrate test*), p. 100.	Darapskite.	$Na_2SO_4.NaNO_3.H_2O$.	Colorless or white.	Vitreous.	C. Pinac., *per.*	2–3	2.20	1 ?	Monocl. Tabular.
		Gives the odor of ammonia when heated in a closed tube with lime (ignited calcite).	Lecontite.	$(Na,NH_4,K)_2SO_4.2H_2O$.	Colorless or white.	Vitreous.		2–2.5		1	Orthorh.
		Gives much water (55 per cent) in the closed tube.	**Mirabilite.** (Glauber Salt.)	$Na_2SO_4.10H_2O$.	Colorless or white.	Vitreous.	C. Pinac., *per.*	1.5–2	1.48	1.5	Monocl.
	Contain *potassium.*—Impart a violet color to the flame, but do not give the reactions of the foregoing divisions.	Has a sour taste.	Misenite.	$HKSO_4$.	Colorless or white.	Vitreous or silky.				1	Fibrous.
		Sparingly soluble in water. Reacts for calcium (p. 60, § 6).	Syngenite.	$CaK_2(SO_4)_2.H_2O$.	Colorless or white.	Vitreous.	C. prism., *per.* F. Conchoidal.	2.5	2.6	1.5–2	Monocl.

Division 1. *Section a.*—Concluded on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives *an alkaline reaction* when placed on moistened turmeric-paper.

Section a.—Easily and completely soluble in water.—Concluded.

Section b.—Insoluble in water, or difficultly or only partially soluble.—In part.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

Part III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic*

Division 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives *an alkaline reaction* when placed on moistened turmeric-paper.

Section a.—Easily and completely soluble in water.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Nitrates. — When heated in a bulb tube with potassium bisulphate, red vapors of NO_2 are given off (p. 100).*	Gives an intense yellow flame (*sodium*).	**SODA NITER.**	$NaNO_3$.	Colorless or white.	Vitreous.	C. Rhombohedral, *per.*	1.5–2	2.29	1	Hex. Rh.
	Gives a violet flame (*potassium*).	**NITER.**	KNO_3.	Colorless or white.	Vitreous.	C. Prism., *per.* F. Conchoidal.	2	2.1–2.15	1	Orthorh. U. acicul.
	Gives a yellowish-green flame (*barium*). Test on platinum wire (p. 35).	Nitrobarite.	$Ba(NO_3)_2$.	Colorless or white.	Vitreous.	F. Uneven.	2.5		1–1.5	Isometric. Cl.5, p.219
Borate.—Give the boracic acid reaction with turmeric-paper (p. 56, § 2).	When taken up in the loop on platinum wire swells when first heated, and fuses finally to a clear glass.	**BORAX.**	$Na_2B_4O_7.10H_2O$.	Colorless or white.	Vitreous.	C. Pinac., *per.* F. Conchoidal.	2–2.5	1.72	1–1.5	Monocl.
Give iodine vapors when heated in a closed tube.	☞ Compare the difficultly soluble iodates, *Lautarite* and *Dietzeite*, in the next section.									

* Nitrates of calcium and magnesium, containing water of crystallization, have been identified.

Section b.—Insoluble in water, or difficultly or only partially soluble.

N.B.—The minerals in this section are chiefly salts of the alkali-earth metals, *calcium*, *strontium* and *barium*, with volatile acids (*carbonic*, *sulphuric*, and *hydrofluoric*). Flame tests may be used advantageously in identifying the metals, and it is recommended to make the tests on platinum wire as directed on p. 35. After the mineral has been fused on the wire, touching it to a drop of hydrochloric acid, and then introducing it into the flame, serves in many cases to bring out the color more decidedly.

Silicates and other compounds which do not properly belong to this section at times give an alkaline reaction after ignition. It will generally be found, however, that such minerals are associated with the common mineral *Calcite* (p. 289), and that the alkaline reaction is due to traces of the calcite which permeate minute cracks in the crystals. If such minerals are thoroughly fused the calcite will be decomposed and a misleading alkaline reaction will not be obtained.

Carbonates.—Dissolve in *dilute* hydrochloric acid with effervescence (p. 62, § 1, also p. 63, § 1, *c*).	Give water in the closed tube. B. B. give an intense yellow flame (*sodium*).	When treated with boiling water, calcium carbonate separates, and the soluble sodium carbonate renders the solution alkaline. Pirssonite exhibits pyroelectricity (p. 231).	**Gay-Lussite.**	$Na_2CO_3.CaCO_3.5H_2O$.	Colorless white, gray.	Vitreous.	C. Prismatic. F. Conchoidal.	2–3	1.99	1.5	Monocl. U. cryst.
			Pirssonite.	$Na_2CO_3.CaCO_3.2H_2O$.	Colorless, white, gray.	Vitreous.	F. Conchoidal.	3–3.5	2.35	1.5	Orthorh. Hemimor.
		Ammonia gives a precipitate of aluminium hydroxide when added to the dilute HCl solution (p. 42, § 2).	Dawsonite.	$Na(Al.2OH)CO_3$.	White.	Vitreous, silky.	F. Longitudinal.	3	2.40	4.5–5	Monocl. Bladed. Radiated.
	Gives water in the closed tube, but does not contain sodium.	The dilute HCl solution gives a precipitate with barium chloride (p. 122), and a residue of silica when evaporated to dryness (p. 109).	Thaumasite.	$CaCO_3.CaSiO_3.CaSO_4.15H_2O$.	White, colorless.	Vitreous.	F. Splintery.	3.5	1.87	5	Hexag. Column., fibrous.
	Give no water in the closed tube.	Gives a yellowish-green color to the flame (*barium*). Test on platinum wire (p. 35).	**WITHERITE.**	$BaCO_3$.	Colorless, white, gray.	Vitreous.	F. Uneven.	3.5	4.3	2.5–3	Orthorh. Twinned.
		Gives an intense yellow flame (*sodium*). Reacts for chlorine (p. 67, § 1) and magnesium (p. 91, § 1).	Northupite.	$MgCO_3.Na_2CO_3.NaCl$.	Colorless, white, brown.	Vitreous.	F. Conchoidal.	3.5–4	2.38	1–1.5	Isometric. Fig. 96.

Division 1.—Concluded on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives *an alkaline reaction* when placed on moistened turmeric-paper.

Section b.—Insoluble in water, or difficultly or only partially soluble.—Concluded.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

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DIVISION 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives *an alkaline reaction* when placed on moistened turmeric-paper.

Section b.—Insoluble in water, or difficultly or only partially soluble.—Concluded.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Sulphates.—Fused on platinum wire with a mixture of Na_2CO_3 and charcoal powder, and then transferred to moistened silver, give a dark stain of *silver sulphide* (p. 122, § 2). Those sulphates which are soluble in HCl give with barium chloride a precipitate of *barium sulphate* (p. 122, § 1).	Give much water in the closed tube. The fine powder is readily soluble in boiling, dilute HCl.	Ammonia gives a precipitate of aluminium hydroxide when added to the HCl solution.	Ettringite.	$(Ca.OH)_6(SO_4)_3.2Al(OH)_3.24H_2O$?	Colorless or white.	Vitreous.	F. Splintery.	2–2.5	1.75	3	Hexag. Needles.
		Gives no decided flame coloration when heated alone B. B.	**GYPSUM.** (Alabaster.)	$CaSO_4.2H_2O$.	Colorless, white, gray.	Vitreous.	C. 3 directions. Pinac., *per.*	2	2.32	3–3.5	Monocl. Page 210.
		Gives a yellow flame (*sodium*).	Wattevillite.	$CaSO_4.Na_2SO_4.4H_2O$. Mg iso. w. Ca, & K w. Na.	White.	Silky, vitreous.			1.81	1.5–2	Acicular.
		Give a violet flame (*potassium*), seen best through blue glass. Polyhalite reacts for magnesium (p. 91, § 1).	**Polyhalite.**	$2CaSO_4.MgSO_4.K_2SO_4.2H_2O$.	Brick-red to yellow.	Vitreous to resinous.	C. Pinacoidal. F. Splintery.	2.5–3	2.77	2	Monocl.? Column.
			Syngenite.	$CaK_2(SO_4)_2.H_2O$.	Colorless or white.	Vitreous.	C. Pinac., *per.* F. Conchoidal.	2.5	2.60	1.5–2	Monocl.
	Give little or no water in the closed tube. Glauberite is readily, and Anhydrite slowly, soluble in boiling dilute HCl, while Celestite and Barite are almost insoluble.	Gives a yellow flame (*sodium*).	**Glauberite.**	$CaSO_4.Na_2SO_4$.	Colorless, white, gray.	Vitreous.	C. Basal, *per.* F. Conchoidal	2.5–3	2.75	1.5–2	Monocl. U. tabul.
		Gives no decided flame coloration when heated alone B. B.	**ANHYDRITE.**	$CaSO_4$.	Colorless, white, blue, gray, red.	Vitreous, pearly.	C. 3 directions (pinacoidal) at 90°, *per.*	3–3.5	2.95	3–3.5	Orthorh. U. mass.
		Gives a crimson flame (*strontium*).	**CELESTITE.**	$SrSO_4$.	Colorless, white, blue, red.	Vitreous, pearly.	C. Basal, *per.* & prismatic.	3–3.5	3.97	3.5–4	Orthorh. Page 202.
		Gives a yellowish-green flame (*barium*).	**BARITE.** (Heavy Spar.)	$BaSO_4$.	Colorless, white, blue, yellow, red.	Vitreous, pearly.	C. Basal, *per.* & prismatic.	3–3.5	4.5	4	Orthorh. Page 201.
	☞ Compare the magnesium sulphates on page 272, some of which may be difficultly soluble in water.										
Fluorides.—When heated with potassium bisulphate in a closed tube of 6 mm. internal diameter, the glass is attacked and a deposit of silica forms on the walls of the tube as explained on p. 76, § 2.	Give little or no water in the closed tube.	Easily fusible. Color the flame yellow (*sodium*). Powdered cryolite is scarcely visible in water because of its low index of refraction.	**CRYOLITE.**	$Na_3AlF_6 = 3NaF.AlF_3$.	Colorless, snow-white, brownish.	Vitreous to greasy.	C. Pinacoidal. F. Uneven.	2.5	2.97	1.5	Monocl. U. mass.
			Chiolite.	$5NaF.3AlF_3$.	Snow-white.	Vitreous.	F. Uneven.	3.5–4	2.9–3.0	1.5	Tetrag. U. mass.
		Gives a reddish flame (*calcium*). Often phosphoresces (p. 231) and decrepitates when heated in the closed tube.	**FLUORITE.** (Fluor Spar.)	CaF_2.	Colorless, violet, green, yellow, pink.	Vitreous.	C. Octahedral, *perfect.* F. Uneven.	4	3.18	3	Isometric. Figs. 95, 96, 98, 112, 115.
	Give *acid* water in the closed tube, often accompanied by etching of the glass, and a deposit of silica (p. 77, § 5). ☞ Compare *Prosopite* (p. 290).	Generally decrepitate to a fine powder when heated in a closed tube. Thomsenolite occurs in rather stout, and Pachnolite in very slender, prisms.	**Thomsenolite.**	$NaCaAlF_6.H_2O$.	Colorless, white, brown.	Pearly, vitreous.	C. Basal, *per.* F. Uneven.	2	2.93	1.5	Monocl. Cryst. & massive.
			Pachnolite.	$NaCaAlF_6.H_2O$.	Colorless or white.	Vitreous.	F. Uneven.	3	2.98	1.5	Monocl. Prismatic
		Occurs as an earthy powder. Contains no sodium.	Gearksutite.	$CaF_2.Al(F,OH)_3.H_2O$.	White.	Dull.		2 ?		1.5–2	Pulverulent. Earthy.
Iodates.—Fuse and give iodine vapors when heated in a closed tube.		*Dietzeite* is readily distinguished by its reaction for chromium with the salt of phosphorus bead.	Lautarite.	$Ca(IO_3)_2$.	Sulphur-yellow to colorless.	Vitreous.	C. Prismatic. F. Conchoidal.	3.5–4	4.59	1.5	Monocl. Prismatic
			Dietzeite.	$7Ca(IO_3)_2.8CaCrO_4$.	Golden-yellow	Vitreous.	F. Uneven.	3–4	3.70	1.5	Monocl. Tabular.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—In part.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic*.

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.

In order to determine whether a mineral belongs to this division treat one or two ivory-spoonfuls of the *finely pulverized* material in a test-tube with from 3 to 5 cc. of hydrocloric acid, and boil until not over 1 cc. remains. The concentrated solution thus obtained should be a *clear liquid* (not thick and gelatinous, indicating a silicate), or, in case any solid material separates from the solution or deposits on the sides of the tube, it should go *wholly* into solution upon addition of water and warming.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Sulphates.—The dilute HCl solution gives with barium chloride a precipitate of *barium sulphate* (p. 122, § 1). The *magnesium sulphates* (p. 272) might possibly be referred to this division, because they give a faint and not very decided alkaline reaction. A number of the sulphates of *aluminium, zinc, manganese* and *nickel* may swell and show signs of fusion when first heated, but after ignition they yield an infusible mass of oxide and will be found, therefore, on subsequent pages devoted to infusible minerals.										
Arsenates.—Give an arsenical mirror when mixed with dry Na_2CO_3 and charcoal powder, and heated intensely B. B. in a closed tube (p. 51, § *b*). Those which are fusible below 2.5 give the arsenic reaction when heated intensely B. B. in a closed tube with fragments of charcoal (p. 51, § *a*).										
Contain *fluorine.*—When heated in a bulb tube with potassium bisulphate, the glass is etched and a deposit of silica forms on the walls of the tube (p. 76, § 2).	Imparts an intense yellow color to the blowpipe flame (*sodium*).	Durangite.	$Na(AlF)AsO_4$. Fe & Mn iso. w. Al.	Light to dark orange-red.	Vitreous.	C. Prismatic. F. Uneven.	5	4.0	2	Monocl.
	Give no decided flame coloration. The concentrated HCl solution gives with dilute H_2SO_4 a precipitate of *calcium sulphate* (p. 59, § 3).	Tilasite.	$Ca(MgF)AsO_4$.	Gray to violet.	Vitreous, greasy.	C. Pinac., *per.*			4–5 ?	Foliated.
		Svabite.	$Ca_4(CaF)(AsO_4)_3$. OH iso. w. F.	Colorless.	Vitreous, greasy.	C. Prismatic.		3.5–3.8	4.5–5	Hexag.
When heated in R. F. on charcoal with a little Na_2CO_3, give a coating of *zinc oxide*.	Gives 3 per cent of water in the closed tube (*hydroxyl*, p. 81, § 1, *b*).	**Adamite.**	$Zn(Zn.OH)AsO_4$.	Pale green, yellow, violet, colorless.	Vitreous.	C. Prismatic. F. Uneven.	3.5	4.35	3	Orthorh.
	Gives 23 per cent of water in the closed tube (*water of crystallization*, p. 81, § 1, *b*).	Köttigite.	$Zn_3(AsO_4)_2.8H_2O$.	Pale-red, pink.	Silky.	C. Pinac., *per.*	2.5-3	3.1	3 ?	Monocl. Fibrous.
Contain *manganese.*—Impart a reddish-violet color to the borax bead in O. F.	Soluble in HCl with evolution of chlorine.	Synadelphite.	$2(Mn,Al)AsO_4.5Mn(OH)_2$. Mg & Ca iso. w. Mn.	Brownish-black to black.	Vitreous, greasy.	F. Uneven.	4.5	3.45–3.5	2–3 ?	Monocl.
		Flinkite.	$MnAsO_4.Mn(OH)_2$.	Greenish-brown.	Vitreous, greasy.		4–4.5	3.87	2–3 ?	Orthorh.
	Soluble in HCl without evolution of chlorine. Berzeliite is anhydrous; the rest give water in the closed tube. The calcium in Berzeliite and Brandtite may be detected by adding a drop of *dilute* H_2SO_4 to the concentrated HCl solution (p. 59, § 3).	Berzeliite.	$(Ca,Mg,Mn)_3(AsO_4)_2$.	Sulphur- to orange-yellow.	Resinous.	F. Uneven.	5	4.08	3	Isometric.
		Brandtite.	$Ca_2Mn(AsO_4)_2.2H_2O$.	Colorless or white.	Vitreous.	F. Uneven.	5–5.5	3.67	2.5–3	Triclinic.
		Larkinite.	$Mn(Mn.OH)AsO_4$.	Flesh-, rose-, or yellowish-red.	Greasy.	C. Prismatic. F. Uneven.	4–5	4.18	2	Monocl.
		Hemafibrite.	$Mn_3(AsO_4)_2.3Mn(OH)_2$.						2 ?	Orthorh.
		Allactite.	$Mn_3(AsO_4)_2.4Mn(OH)_2$.	Brownish-red.	Vitreous, greasy.	C. One direc. F. Uneven.	4.5	3.84	2 ?	Monocl.
Contains *cobalt.*—Imparts a blue color to the borax bead.	Reacts for *calcium* when a drop of *dilute* H_2SO_4 is added to the concentrated HCl solution (p. 59, § 3).	Roselite.	$(Ca,Co,Mg)_3(AsO_4)_2.2H_2O$.	Rose-red.	Vitreous.	C. Pinacoidal.	3.5	3.5–3.6	3	Triclinic.
Contain *uranium.*—Give a green color to the salt of phosphorus bead in R. F. Uranospinite contains calcium, but the test with H_2SO_4 (p. 59, § 3) must be made very carefully, as the amount is small.		Trögerite.	$(UO_2)_3(AsO_4)_2.12H_2O$.	Lemon-yellow.		C. Pinac., *per.*		3.3	2.5	Monocl. U. tabul.
		Uranospinite.	$Ca(UO_2)_3(AsO_4)_2.8H_2O$.	Bright-green.		C. Basal, *per.*	2–3	3.45		Orthorh. U. tabul.
Contain *calcium*, but do not give the reactions of the foregoing divisions.—The concentrated HCl solution gives a precipitate of *calcium sulphate* upon addition of a drop of *dilute* H_2SO_4 (p. 59, § 3).		Adelite.	$Ca(Mg.OH)AsO_4$	Gray.			5	3.76		Monocl.
		Haidingerite.	$HCaAsO_4.H_2O$.	White.	Pearly, vitreous.	C. Pinac., *per.*	1.5–2.5	2.85	2.5	Orthorh.
		Pharmacolite.	$HCaAsO_4.2H_2O$.	White or grayish.		C. Pinac., *per.* F. Uneven.	2–2.5	2.6-2.7	2.5	Monocl. U. fibrous.
Ammonia when added to the dilute HCl solution gives a crystalline precipitate of *ammonium magnesium arsenate.*		Hœrnesite.	$Mg_3(AsO_4)_2.8H_2O$.	Snow-white.	Pearly.	C. Pinac., *per.*	1	2.47	2–3 ?	Monocl

DIVISION 2.—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—Continued.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—Continued.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Phosphates.—Give a yellow precipitate of *ammonium phosphomolybdate* when a few drops of the HNO_3 solution are added to ammonium molybdate (p. 102, § 1). When ammonium molybdate is not at hand, the pale *bluish-green* flame coloration, often seen only after moistening the assay with sulphuric acid, may be used to identify the phosphate. ☞ *Phosphates* concluded on next page.	Contain *uranium.*—Impart a green color to the salt of phosphorus bead in R. F.	Autunite and Uranocircite react for calcium and barium, respectively, when their HCl solutions are treated with *dilute* H_2SO_4 (p. 59, § 3, and p. 52, § 3).	**Autunite.**	$Ca(UO_2)_2(PO_4)_2.8H_2O$.	Lemon- to sulphur-yellow.	Pearly to subadamantine.	C. Basal, *per.*	2–2.5	3.05–3.2	3	Orthorh. Tabular.
			Uranocircite.	$Ba(UO_2)_2(PO_4)_2.8H_2O$.	Yellowish-green.	Pearly to subadamantine.	C. Basal, *per.*	2–2.5	3.53	3 ?	Orthorh. Tabular.
			Phosphuranylite.	$(UO_2)_3(PO_4)_2.6H_2O$	Deep lemon-yellow.	Pearly.				3–4 ?	Pulverulent.
	Contain *manganese.*—Impart a reddish-violet color to the borax bead in O. F. Ferrous iron (isomorphous with the manganese) is present in almost all cases. Test with potassium ferricyanide as directed on p. 85, § 4. When calcium is present it may be detected by adding a drop of *dilute* H_2SO_4 to the concentrated HCl solution (p. 59, § 3).	Gives a red flame (*lithium*), tried best on platinum wire (p. 35).	**Lithiophilite.** See *triphylite*, p. 268.	$Li(Mn,Fe)PO_4$.	Salmon-color, clove-brown.	Resinous.	C. Basal, *per.* & pinacoidal.	4.5–5	3.48	2–2.5	Orthorh.
		Give an intense yellow flame (*sodium*), and no water or only a little in the closed tube.	Natrophilite.	$Na(Mn,Fe)PO_4$.	Deep wine-yellow.	Resinous.	C. Basal, *per.*	4.5–5	3.41	2–2.5	Orthorh.
			Dickinsonite.	$(Mn,Fe.Ca,Na_2)_3(PO_4)_2.\frac{1}{3}H_2O$.	Olive-, oil-, or grass-green.	Vitreous, pearly.	C. Basal, *per.*	3.5–4	3.34	2.5–3	Monocl. Foliated.
			Fillowite.	$(Mn,Fe,Ca,Na_2)_3(PO_4)_2.\frac{1}{3}H_2O$.	Wax-yellow to brown.	Greasy.	C. Basal. F. Uneven.	4.5	3.43	2.5–3	Monocl.
		B. B. cracks open, swells and whitens, then fuses to a dark brown or black mass.	Eosphorite. See *childrenite*, p. 268.	$(Mn,Fe)(Al.2OH)PO_4.H_2O$.	Delicate rose-pink.	Vitreous, resinous.	C. Pinacoidal. F. Uneven.	5	3.12	4	Orthorh.
		Fuses to an orange or reddish-yellow globule.	Hureaulite.	$H_2(Mn,Fe)_5(PO_4)_4.4H_2O$.	Pale-rose, orange, brown.	Vitreous, greasy.	C. Pinacoidal.	5	3.18	3	Monocl.
		Contains much calcium.	Fairfieldite.	$Ca_2Mn(PO_4)_2.2H_2O$ Fe iso. w. Mn.	Colorless to greenish-white.	Pearly to subadamantine.	C. Pinac., *per.*	3.5	3.15	4–4.5	Triclinic.
		Contains only traces of calcium.	Reddingite.	$Mn_3(PO_4)_2.3H_2O$. Fe iso. w. Mn.	Pale-rose to brown.	Vitreous to resinous.	F. Uneven.	3–3.5	3.10	2.5–3	Orthorh.
	Contain *much calcium.*—In the concentrated HCl solution a precipitate of *calcium sulphate* forms upon addition of a drop of *dilute* sulphuric acid (p. 59, § 3). ☞ Compare *Bobierrite* (p. 277), which may contain a little calcium.	Anhydrous. Gives a slight reaction for fluorine (p. 76, § 2), and often also for chlorine (p. 67, § 1).	**APATITE.**	$Ca_4(CaF)(PO_4)_3$. Cl iso. w. F. Rarely Mn iso. w. Ca.	Green, blue, violet, brown, colorless.	Vitreous, greasy.	C. Basal. F. Uneven.	5	3.15	5–5.5	Hexag., Page 189.
		Gives a little water when *intensely heated* in the closed tube, and also vapors of hydrofluoric acid which etch the glass (p. 77, § 5).	**Herderite.**	$Ca[Be(OH,F)]PO_4$.	White to pale-green or yellow.	Vitreous to resinous.	F. Uneven.	5	3.00	4	Monocl.
		Give a little water in the closed tube (not over 7 per cent). That the quantity of water is small may be determined by comparing the closed-tube test with one made upon an equally large fragment of gypsum which has 21 per cent of water.	**Hydro-herderite.**	$Ca(Be.OH)PO_4$.	White, pale-green, yellow.	Vitreous to resinous.	F. Uneven.	5	2.95	4	Monocl.
			Cirrolite.	$(Ca.OH)_3Al_2(PO_4)_3$.	White to pale yellow.	Vitreous.	F. Uneven.	5–6	3.08	4	Massive.
			Monetite.	$HCaPO_4$.	Yellowish-white.	Vitreous.	C. Pinacoidal. F. Uneven.	3.5	2.75	3	Triclinic.
			Collophanite.	$Ca_3(PO_4)_2.H_2O$.	Colorless, white, yellow.	Dull.	F. Conchoidal.	2–2.5	2.70	4.5–5 ?	Amorph.
		Give *much* water in the closed tube (20 per cent or over). Compare the quantity of water with that obtained from gypsum which has 21 per cent.	Isoclasite.	$Ca(Ca.OH)PO_4.2H_2O$	Colorless or white.	Vitreous, pearly.	C. Pinac., *per.*	1.5	2.92	4 ?	Monocl.
			Brushite.	$HCaPO_4.2H_2O$.	Colorless to pale-yellow.	Vitreous, pearly.	C. Pinac., *per.*	2–2.5	2.20	3	Monocl.

DIVISION 2.—Concluded on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—Concluded.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—Concluded.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Phosphates.—Concluded. Do not give the foregoing reactions for uranium, manganese and calcium. ☞ A few phosphates which are difficultly soluble in HCl will be found in Division 5, p. 283.		Gives an intense yellow flame (*sodium*). Anhydrous.	Beryllonite.	$NaBePO_4$.	Colorless or white	Vitreous, pearly.	C. Basal, *per.* F. Conchoidal.	5.5–6	2.84	3–3.5	Orthorh.
		Gives a reaction for fluorine (p. 76, § 2). Contains little or no water.	Wagnerite.	$Mg(MgF)PO_4$.	Pale-yellow, gray or red.	Vitreous.	F. Uneven.	5–5.5	3.06	3.5–4	Monocl.
		In the closed tube give water and the odor of ammonia.	Struvite.	$NH_4MgPO_4.6H_2O$.	White, yellow, brown.	Vitreous.	F. Uneven.	2	1.65	3	Orthorh. Hemimor.
			Stercorite. (Salt of Phosphorus.)	$H(NH_4)NaPO_4.4H_2O$.	White, yellow, brown.	Vitreous.		2	1.61	1	Monocl.
		Gives a coating of *oxide of zinc* when heated with a little Na_2CO_3 on charcoal in R. F.	Hopeite.	$Zn_3(PO_4)_2.4H_2O$.	Grayish-white.	Vitreous.	C. Pinac., *per.* F. Uneven.	2.5–3	2.75–2.8	3–4 ?	Orthorh.
		Reacts for boron (p. 56, § 2).	Lüneburgite.	$Mg_3(PO_4)_2.B_2O_3.8H_2O$.	White.				2.05		Fibrous. Earthy.
		Ammonia, when added to the dilute HCl solution, gives a crystalline precipitate of *ammonium magnesium phosphate.*	Bobierrite. (Hautefeuillite, when containing (Ca iso. w. Mg.)	$Mg_3(PO_4)_2.8H_2O$. Ca iso. w. Mg.	Colorless or white.		C. Pinacoidal.	2.5	2.43		Monocl.
Borates.—Turmeric paper, when moistened with a dilute HCl solution of the mineral and dried at 100° C. (on the outside of a test-tube containing boiling water), assumes a reddish-brown color. Most borates impart a green color to the blowpipe flame.	Give little or no water in the closed tube. The remaining borates contain water.	Colors the flame green. Reacts for *chlorine* when fused with Na_2CO_3, dissolved in dilute HNO_3 and tested with silver nitrate (p. 67, § 1).	**Boracite.**	$Mg_7Cl_2B_{16}O_{30}$.	Colorless, white, gray, green.	Vitreous.	F. Conchoidal.	7	2.9–3.0	3	Isom. Tet. Page 175.
		B. B. gives a green flame. Reacts for *potassium* (p. 105, § 1, *c*).	Rhodizite.	$K(AlO)_2(BO_2)_3$.	Colorless or white.	Vitreous.		8	3.41	4.5–5	Isom. Tet.
		Imparts a reddish-violet color to the borax bead in O. F. (*manganese*).	Pinakiolite.	$3MgB_2O_4.Mn''Mn'''_2O_4$.	Black.	Sub-metallic.	C. Pinacoidal.	6	3.88	5	Orthorh. Tabular.
	Readily soluble in water.	B. B. fuses with much swelling and imparts a yellow color to the flame (*sodium*).	**BORAX.**	$Na_2B_4O_7.10H_2O$.	Colorless or white.	Vitreous.	C. Pinac., *per.* F. Conchoidal.	2–2.5	1.75	1–1.5	Monocl.
		Slowly volatilizes B. B., tinging the flame green.	**Sassolite.** (Boracic Acid.)	$B(OH)_3$.	Colorless or white.	Pearly.	C. Basal, *per.*	1	1.48	0.5	Triclinic, U. tabular
	Imparts a reddish-violet color to the borax bead in O. F. (*manganese*).	Colors the flame green.	Sussexite.	$H(Mn,Mg,Zn)BO_3$.	Gray.	Silky.	F. Splintery.	3	3.12	2.5	Orthorh.? Fibrous.
	Contain *calcium.*—The dilute HCl solution, after being made alkaline with ammonia, gives a precipitate with ammonium oxalate (p. 60, § 6). N.B.—If the HCl solution is too concentrated the addition of ammonia may cause a precipitate of calcium borate.	B. B. exfoliates, crumbles and colors the flame green.	**Colemanite.**	$Ca_2B_6O_{11}.5H_2O$.	Colorless or white.	Vitreous.	C. Pinac., *per.* F. Uneven.	4–4.5	2.42	1.5	Monocl.
		B. B. fuses to a clear glass, and colors the flame green.	Hydroboracite.	$CaMgB_6O_{11}.6H_2O$.	White.	Vitreous, silky.	C. One direction.	2	1.9–2.0	1.5 ?	Fibrous, foliated.
		B. B. colors the flame yellow (*sodium*).	**Ulexite.**	$NaCaB_5O_9.8H_2O$.	White.	Silky.		1	1.65	1.5	Fibrous.
		B. B. colors the flame reddish-yellow (?).	Bechilite.	$CaB_4O_7.4H_2O$.						1.5 ?	Massive.
	Contain *magnesium.*—The dilute HCl solution, when made strongly alkaline with ammonia, gives a precipitate with sodium phosphate (p. 91, § 1).	B. B. cracks open, glows and fuses to a pale, horn-like, brownish-gray mass.	Szaibelyite.	$Mg_5B_4O_{11}.1\frac{1}{2}H_2O$.	White to yellow.			3–4	3.0		Nodular. Acicular.
		B. B. fuses quietly at 3, coloring the flame green.	Pinnoite.	$MgB_2O_4.3H_2O$.	Sulphur- or straw-yellow.	Vitreous.		3–4	3.3	3	Tetrag. Cl. 20, p.219.
		B. B. fuses very easily and colors the flame green.	Heintzite.	$KMg_2B_{11}O_{19}.7H_2O$.	Colorless or white.	Vitreous.	C. Pinac. & basal, *per.*	4–5	2.13	1	Monocl.
Molybdates.—Give the reduction test described on p. 96, § 4.		The dilute HCl solution, made alkaline with ammonia, gives a precipitate either with ammonium oxalate (p. 60, § 6, Powellite) or with sodium phosphate (p. 91, § 1, Belonesite).	Powellite.	$CaMoO_4$. W iso. w. Mo.	Colorless, green, yellow.	Resinous.	F. Uneven.	3.5	4.52	4	Tetrag. Cl. 20, p.219
			Belonesite.	$MgMoO_4$.	Colorless, white.					4–5	Tetrag.
Sulphides.—Give the odor of sulphurous anhydride, SO_2, when roasted in the open tube.		Sphalerite ZnS, which becomes rounded B. B. owing to the volatilization of the zinc, but does not fuse, is classed on p. 292. The dark-colored manganese sulphides Alabandite MnS, and Hauerite MnS_2, are classed on p. 253.									

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

Part III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

Division 3.—Soluble in hydrochloric acid, and yield *gelatinous silica* upon evaporation.

Section a.—In the closed tube give water.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 3.—Soluble in hydrochloric acid, and yield *gelatinous silica* upon evaporation.

In order to determine that a mineral belongs to this division treat one or two ivory-spoonfuls of the *finely powdered* material in a test-tube with from 3–5 c.c. of hydrochloric acid, and boil until not over 1 c.c. remains. The mineral should go wholly into solution, unless difficultly soluble, and when the volume becomes small the contents of the tube should *thicken,* owing to the separation of *gelatinous silicic acid* (p. 108, § 1). The silicic acid thus separated will not go into solution when treated with additional water or acid.

Section a.—In the closed tube give water.—Silicates containing *water of crystallization* or the *hydroxyl radical.*

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
B. B. fuses to a clear glass, coloring the flame green. Gives a little water in the closed tube.		**DATOLITE.**	$Ca(B.OH)SiO_4$.	Colorless, pale-green, yellow.	Vitreous.	F. Uneven.	5–5.5	2.9–3.0	2–2.5	Monocl. U. cryst.
The dilute HCl solution gives with H_2SO_4 a precipitate of barium sulphate.		Edingtonite.	$BaAl(Al.2OH)(SiO_3)_3.2H_2O$.	Colorless, white, pink.	Vitreous.	C. Prism., *per.* F. Uneven.	4–4.5	2.77	2.5	Orthorh. Cl.27, p. 219.
Imparts a reddish-violet color to the borax bead in O. F. (*manganese*). Has a decidedly *micaceous* structure.		Ganophyllite.	$Mn_7(AlO)_2(SiO_3)_8.6H_2O$.	Brown.	Vitreous.	C. Basal, *per.*	4–4.5	2.84	3	Monocl. Foliated.
Gives a coating of *oxide of zinc* when fused on charcoal with a little Na_2CO_3.	B. B. whitens and fuses with difficulty.	**CALAMINE.**	$(Zn.OH)_2SiO_3$.	White, pale-green, or blue.	Vitreous.	C. Prism., *per.* F. Uneven.	4.5–5	3.45	5	Orthorh. Page 207.
	B. B. fuses to a yellow globule.	Clinohedrite.	$H_2CaZnSiO_5$.	Amethystine to white.	Vitreous.	C. Pinac., *per.* F. Uneven.	5–6	3.33	4	Monocl. Cl.30, p. 219.
Contain the *carbonate radical.*—A fragment dissolves with effervescence in warm dilute HCl.	B. B. swells, froths and fuses to a vesicular globule. In the closed tube whitens and gives water.	**Cancrinite.**	$H_6(Na_2,Ca)_4(Al.NaCO_3)_2Al_6(SiO_4)_9$.	Yellow, pink, gray, white.	Vitreous, greasy.	C. Prismatic. F. Uneven.	5–6	2.4–2.5	2.5–3	Hexag. U. mass.
	Gives the reactions of the rare-earth metals (p. 65).	Cenosite. (Kainosite.)	Uncertain. Si,Y,Ca,O,CO_2,H_2O	Yellowish-brown.	Greasy.	C. Pinacoidal.	5–5.5	3.41	5 ?	Orthorh.
Contain little or no *calcium.*—After separation of the silica and alumina (p. 110, § 4), ammonium oxalate produces little or no precipitate in the ammoniacal filtrate (p. 60, § 6).	Fuses quietly to a clear, transparent glass.	**NATROLITE.**	$Na_2Al(AlO)(SiO_3)_3.2H_2O$.	Colorless or white.	Vitreous.	C. Prism., *per.* F. Uneven.	5–5.5	2.25	2.5	Orthorh. Prismatic
	Fuses easily to a white enamel.	Hydronephelite.	$HNa_2Al_3(SiO_4)_3.3H_2O$.	White to dark-gray.	Vitreous.		4.5–6	2.3–2.5	2–3	Hexag.
	Fuses to a glassy enamel. Gives a reaction for magnesium (p. 91, § 1).	Spadaite.	$H_2Mg_5(SiO_3)_6.3H_2O$.	Flesh-red.	Pearly, greasy.	F. Splintery.	2.5		4 ?	Massive.
Contain *aluminium* and *calcium.*—In the HCl solution, after separation of the silica (p. 108, § 1), ammonia produces a precipitate of *aluminium hydroxide* (p. 42, § 2), and in the filtrate ammonium oxalate produces a precipitate of *calcium oxalate* (p. 60, § 6). ☞ Compare *Allanite* (p. 280) which may contain water if impure.	Fuses to a voluminous, frothy slag. Exhibits pyroelectricity (p. 231).	**Scolecite.**	$CaAl(Al.2OH)(SiO_3)_3.2H_2O$.	Colorless or white.	Vitreous.	C. Prismatic.	5–5.5	2.16–2.4	2.5	Monocl. Prismatic.
	Fuse with intumescence to white vesicular globules. Do not exhibit pyroelectricity. Mesolite contains both the natrolite and scolecite molecules.	**Mesolite.**	Approx. $Na_2Ca_2Al_6Si_9O_{30}.8H_2O$	White, gray, yellow.	Vitreous, silky.	C. Prism., *per.*	5	2.2–2.4	2–2.5	Monocl. Column.
		Thomsonite. (Comptonite.)	$(Ca,Na_2)Al_2(SiO_4)_2.2\frac{1}{2}H_2O$.	Colorless, white, gray.	Vitreous, pearly.	C. Pinac., *per.* F. Uneven.	5–5.5	2.3–2.4	2–2.5	Orthorh.
		Levynite.	$CaAl(Al.2OH)(SiO_3)_3.4H_2O$.	White, gray, red.	Vitreous.	F. Uneven.	4–4.5	2.0–2.16	2–2.5	Hex. Rh.
	Usually found in simple prismatic crystals with oblique terminations.	**Laumontite.**	$Ca(Al.2OH)_2(Si_2O_5)_2.2H_2O$.	White, gray.	Vitreous, pearly,	C. Pinacoidal & prismatic, *per.*	3.5–4	2.25–2.35	2.5	Monocl. Prismatic
	Occurs in complex, twin crystals, resembling tetragonal pyramids.	Gismondite.	$(Ca,K_2)Al_2(SiO_3)_4.4H_2O$?	Colorless or white.	Vitreous.	F. Uneven.	4.5	2.26	3	Monocl. Twinned.
Contain *little or no aluminium.*—After dissolving in HCl and separating the silica (p. 108, § 1) the solution gives no, or only a slight, precipitate with ammonia.	Gives a poor jelly with HCl. B. B. fuses to a clear glass.	**Pectolite.**	$HNaCa_2(SiO_3)_3$.	Colorless, white, gray.	Vitreous, pearly.	C. Pinac., *per.* F. Splintery.	5	2.7–2.8	2.5–3	Monocl. Fig. 361.
	Fusible to a blebby glass.	**Okenite.**	$H_2Ca(SiO_3)_2.H_2O$.	White, cream, bluish-white.	Dull, pearly.	F. Splintery.	4.5–5	2.28	2.5	Fibrous. Compact.
		Gyrolite.	$H_2Ca_2(SiO_3)_3.H_2O$.	White.	Vitreous, pearly.		3–4		3	Radiated.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 3.—Soluble in hydrochloric acid, and yield *gelatinous silica* upon evaporation.

Section b.—In the closed tube give little or no water.—In part.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 3.—Soluble in hydrochloric acid, and yield *gelatinous silica* upon evaporation.

Section b.—In the closed tube give little or no water.—Anhydrous silicates, or those containing only a little hydroxyl.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain the *sulphide radical.*—Dissolve in HCl with slight evolution of *hydrogen sulphide,* which may be detected by its disagreeable odor.	Imparts to the borax bead in O. F. a reddish-violet color (*manganese*). ☞ Compare *Danalite,* pp. 269 and 294	Helvite.	$R_5(R_2S)(SiO_4)_3$. R = Be, Mn & Fe.	Yellow, brown, green, red.	Vitreous, resinous.	F. Uneven.	6–6.5	3.2–3.35	4–4.5	Isom. Tet.
	B. B. gives an intense yellow flame (*sodium*). Reacts for a sulphate (p. 122, § 1).	**Lazurite.** (Lapis-Lazuli.)	$(Na_2,Ca)_2(Al.NaS_3)Al_2(SiO_4)_3$. $(Al.NaSO_4)$ iso. w. $(Al.NaS_3)$.	Deep azure-blue, greenish-blue.	Vitreous.	F. Uneven.	5–5.5	2.4–2.45	3.5	Isometric. U. mass.
Contain *chlorine.*—The HNO_3 solution gives with silver nitrate a precipitate of *silver chloride.* B. B. color the blowpipe flame intensely yellow (*sodium*).	Fuses to an opaque, greenish bead. The HCl solution gives with turmeric-paper the zirconium reaction (p. 133).	**Eudialyte.** (Eucolite.)	Uncertain. Si,Zr,Na,Ca,Fe″, Ce,Mn,Cl,(OH).	Rose- to brownish-red, brown.	Vitreous.	C. Basal, *per.* F. Splintery.	5–5.5	2.9–3.0	3	Hex. Rh.
	The dilute HCl solution gives a precipitate with barium chloride (*sulphate,* p. 122, § 1).	Microsommite.	Uncertain. Si,Al,Ca,Na,K,O,Cl, $(SO_4),(CO_3)$.	Colorless, white.	Vitreous.	C. Prism., *per.* F. Uneven.	6	2.45–2.5	3.5	Hexag. Prismatic.
	Does not give the foregoing reaction for a sulphate. Fuses to a colorless glass.	**Sodalite.**	$Na_4(AlCl)Al_2(SiO_4)_3$.	White, gray, blue, green.	Vitreous, greasy.	C. Dodecahed. F. Conchoidal.	5.5-6	2.15–2.3	3.5–4	Isometric.
Contain the *sulphate radical.*—The dilute HCl solution gives a precipitate with barium chloride (p. 122, §1).	Haüynite is distinguished from Noselite by containing considerable calcium. Test as directed on p. 110, § 4.	Haüynite. (Haüyne.)	$(Ca,Na_2)_2(Al.NaSO_4)Al_2(SiO_4)_3$.	Blue, green, yellow, white	Vitreous.	C. Dodecahed. F. Uneven.	5.5–6	2.4–2.5	4–4.5	Isometric.
		Noselite. (Nosean.)	$Na_4(Al.NaSO_4)Al_2(SiO_4)_3$.	Gray, green, blue, brown.	Vitreous.	F. Uneven.	5.5	2.25–2.4	3.5–4	Isometric.
Contain *boron.*—Give the boron reaction with turmeric-paper (p. 56, § 2).	Swells, and fuses with difficulty to a white enamel.	Cappelenite.	$BaY_6B_6Si_3O_{25}$.	Greenish-brown.	Vitreous, greasy.	F. Conchoidal.	6–6.5	4.41	4–5	Hexag.
	Intumesces and fuses to a black glass.	Homilite.	$(Ca,Fe)_3(BO)_2(SiO_4)_2$.	Brownish-black to black.	Resinous, vitreous.	F. Uneven.	5	3.38	2	Monocl.
Contain *manganese.*—Impart to the borax bead in O. F. a reddish-violet color.	The *fine powder* when fused on charcoal with a little Na_2CO_3 gives a coating of *oxide of zinc.*	**TROOSTITE.** See *willemite,* p. 294.	$(Zn,Mn)_2SiO_4$.	Apple-green, flesh-red, brown.	Vitreous.	C. Basal & prismatic. F. Uneven.	5.5	4.18	4.5–5	Hex. Rh. Page 196.
	Contains little or no zinc.	**Tephroite.**	Mn_2SiO_4. Mg, Fe, Ca, & Zn iso. w. Mn.	Smoky-gray, brownish-red	Vitreous, greasy.	C. Pinacoidal. F. Uneven.	5.5–6	4–4.12	3–3.5	Orthorh. U. mass.

DIVISION 3, *Section b.*—Concluded on next page

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PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 3.—Soluble in hydrochloric acid, and yield *gelatinous silica* upon evaporation.

Section b.—In the closed tube give little or no water.—Concluded.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

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DIVISION 3.—Soluble in hydrochloric acid, and yield *gelatinous silica* upon evaporation.

Section b.—In the closed tube give little or no water.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain *titanium.*—The HCl solution when boiled with tin assumes a violet color.	Fuses quietly. ☞ Compare *Andradite* (p. 269).	Schorlomite. (Melanite.)	$Ca_3(Fe,Ti,Al)_2[(Si,Ti)O_4]_3$.	Black.	Vitreous.	F. Uneven.	7–7.5	3.88	4	Isometric.
	Fuse with intumescence. After separation of the silica, the reactions for the rare-earth metals may be obtained (p. 65).	Tscheffkinite.	Uncertain. Si, Ti, Th, Ce, Fe, Ca, O.	Velvet-black.	Vitreous.	F. Uneven.	5–5.5	4.55	4	Massive.
		Rinkite.	$Na_9Ca_{11}Ce_3(TiF_2)_4(SiO_4)_{12}$.	Yellowish-brown, straw-yellow.	Vitreous, greasy.	C. Pinacoidal.	5	3.46		Monocl.
Contains *niobium.*—The HCl solution when boiled with tin assumes a blue color (p. 99, § 1).	The HCl solution imparts an orange color to turmeric-paper (*zirconium*, p. 133).	Wöhlerite.	Uncertain. Si, Zr, Nb, Ca, Na, O.	Light yellow to brown.	Vitreous, resinous.	C. Pinacoidal. F. Conchoidal.	5.5–6	3.44	3–3.5	Monocl.
Contains *zirconium.*—Gives the zirconium reaction with turmeric-paper (p. 133).	Fuses to a yellowish-white enamel. ☞ Compare *Eudialyte* (p. 279).	Hiortdahlite.	$(Na_2,Ca)(Si,Zr)O_3$?	Straw-yellow, yellowish-brown.	Vitreous, greasy.	F. Uneven.	5.5–6	3.26	3?	Triclinic.
Contains the *rare-earth metal yttrium* (p. 65).	B. B. swells, cracks apart, and often glows.	**Gadolinite.**	$FeBe_2Y_2Si_2O_{10}$.	Greenish- to brownish-black.	Vitreous, greasy.	F. Conchoidal, splintery.	6.5–7	4.2–4.5	5	Monocl.
Contain *aluminium* and in some cases also *calcium*, but do not give the reactions of the foregoing divisions.—In the HCl solution, after separation of the silica (p. 108, § 1), ammonia produces a precipitate of *aluminium hydroxide* (p. 42, § 2) When calcium is present it may be precipitated in the filtrate from the aluminium by means of ammonium oxalate (p. 60, § 6).	Very easily soluble in HCl. B. B. gives a strong yellow flame (*sodium*).	**NEPHELITE.** (Nepheline, Elæolite.)	$(Na_2,K_2,Ca)_4Al_8Si_9O_{34}$. Approx. $NaAlSiO_4$.	Colorless, gray, greenish, reddish.	Vitreous, greasy.	C. Prismatic. F. Uneven.	5.5–6	2.55–2.65	4	Hexag. Class 11, Page 219.
	Rather difficultly soluble in HCl. Gives little color to the blowpipe flame. ☞ Compare *The Feldspars* (p. 285).	**ANORTHITE.** (Lime Feldspar.)	$CaAl_2(SiO_4)_2$.	Colorless, white, gray.	Vitreous.	C. Basal, *per.* & pinacoidal. F. Uneven.	6–6.5	2.75	4.5	Triclinic.
	Fuses to a white enamel.	Sarcolite.	$(Ca,Na)_3Al_2(SiO_4)_3$.	Flesh- to rose-red, white.	Vitreous.	F. Conchoidal.	6	2.5–2.9	2.5–3?	Tetrag. Cl. 20, p. 219.
	Fuses with slight intumescence to a greenish or yellowish glass.	**Melilite.**	Uncertain. Si, Al, Fe, Ca, Mg, Na, O.	Green, yellow, brown, white.	Vitreous, resinous.	C. Basal. F. Uneven.	5	2.9–3.1	4	Tetrag.
	Fuses with intumescence to a dark slag. Gives reactions for the rare-earth metals (p. 65).	**Allanite.**	$R''_2(R'''.OH)R'''_2(SiO_4)_3$. R'' = Ca & Fe. R''' = Al, Fe, Ce, La, & Di.	Brown to pitch-black.	Resinous, vitreous.	F. Uneven to conchoidal.	5.5–6	3.5–4.2	2.5	Monocl. U. mass.
	Fuses with difficulty to a grayish mass.	Gehlenite.	$(Ca,Mg,Fe)_3Al_2Si_2O_{10}$.	Grayish-green to brown.	Vitreous, resinous.	F. Uneven.	5.5–6	2.9–3.0	4.5–5	Tetrag.
Gives a reaction for *magnesium* after the separation of silica and calcium (p. 91, § 1, *b*).	Difficultly fusible.	**Monticellite.**	$CaMgSiO_4$. Fe iso. w. Mg.	Colorless, to pale yellow or green.	Vitreous.	C. Pinacoidal. F. Uneven.	5–5.5	3.1	5	Orthorh.

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B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 4.—Decomposed by hydrochloric acid *with the separation of silica,* **but without** the formation of a jelly.

Section a.—In the closed tube give water.—In part.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 4.—Decomposed by hydrochloric acid *with the separation of silica,* but without the formation of a jelly.

In order to determine that a mineral belongs in this division treat one or two ivory-spoonfuls of the *finely powdered* material in a test-tube with from 3 to 5 cc. of hydrochloric acid, and boil unti less than 1 cc. of acid remains. The behavior during this treatment should be carefully observed. When the powder is first shaken up with the cold acid the liquid will generally appear milky, owin to the fine, suspended material; when boiled, however, the liquid becomes translucent, although the separated silica prevents it from becoming perfectly clear. After a little experience one can usuall decide from appearances whether the insoluble material is *separated silica* or the *undecomposed mineral;* in order to decide definitely, however, proceed as follows: Add a drop of nitric acid in orde to oxidize any iron that may be present, dilute with 5 cc. of water, boil, and filter, when, if decomposition has taken place, the bases will be in the filtrate. Ammonia, added in excess to the solution will precipitate aluminium and iron which may be filtered off. In the strongly ammoniacal filtrate ammonium carbonate and sodium phosphate will precipitate calcium and magnesium, respectively while if other bases are present (sodium, potassium and lithium excepted) one or the other of the reagents previously mentioned will be very sure to produce a precipitate. For more complete detail for testing for the bases see p. 110, § 4. There are some minerals which are slowly attacked by acids and give, consequently, slight precipitates of the bases when tests are made with ammonia, ammonium carbonate and sodium phospate; the minerals in this division, however, are *readily decomposed* by acids.

Section a.—In the closed tube give water.—Silicates containing *water of crystallization* or the *hydroxyl radical.*

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Structure micaceous. Exfoliates prodigiously when heated B. B. Under the name **Vermiculite** a number of silicates of *aluminium* and *magnesium* are included which have resulted generally from the decomposition or alteration of different kinds of mica. Their composition cannot be expressed by simple formulas. See *The Micas* (p. 284).		**Vermiculite.** (Jefferisite.)	Uncertain. $Si, Al, Mg, O, (H_2O)$. Fe iso. w. Al & Mg.	Yellow, brown, light to dark green.	Pearly.	C. Basal, *per.*	1–1.5	2.2–2.3	4–4.5	Monocl. ? Micaceous, foliated.
Fuses quietly to a white enamel. The HCl solution colors turmeric-paper orange-yellow (*zirconium,* p. 133).		Catapleiite.	$H_4(Na_2,Ca)ZrSi_3O_{11}$	Yellow-brown, gray, violet.	Vitreous.	C. prism., *per.* F. Conchoidal.	6	6.28	2.5	Hexag.
Fuses with slight intumescence to a brown glass. The water in the closed tube gives an acid reaction with test-paper (*fluorine*). Gives reactions for the rare-earth metals (p. 65).		Mosandrite.	$H_{12}Na_2Ca_{10}Ce_2[(Ti,Zr)(OH,F)_2]_4(SiO_4)_{12}$.	Reddish- to greenish-brown.	Greasy, resinous.	C. One direction.	4	2.9–3.0	2.5–3	Monocl. ?
Difficultly fusible. The HCl solution, if sufficiently dilute, gives no or only a slight precipitate with ammonia and ammonium carbonate, but gives an abundant precipitate with sodium phosphate (*magnesium,* p. 91, § 1, *b*).	Compact, with fine earthy texture.	Sepiolite. (Meerschaum.)	$H_4Mg_2Si_3O_{10}$.	White to grayish-white.	Dull.	F. Uneven.	2–2.5	2.0	5	Compact, Earthy.
	Somewhat resembles a gum.	**Deweylite.** (Gymnite.)	$H_4Mg_4(SiO_4)_3.4H_2O$ Ni iso. w. Mg.	Yellow, brown, apple-green	Resinous.	F. Uneven, conchoidal.	3-4	2.40	4–5	Amorph.
	Commonly in compact, greenish masses. Sometimes fibrous (Chrysotile, Fig. 360, p. 221) or foliated (Marmolite)	**SERPENTINE.** (Chrysotile, Serpentine - asbestus, Marmolite.)	$H_4(Mg,Fe)_3Si_2O_9$.	Olive- to blackish-green, yellowish-green, white.	Greasy, wax-like.	F. Uneven, splintery.	2.5–5 U. 4	2.5–2.65	5–5.5	Massive. Pseudomorphous (p. 220).
Contain *manganese.*—Impart to the borax bead in O. F. a reddish-violet color.	Gives a reaction for chlorine when tested as directed on p. 68, § 3.	Friedelite.	$H_7(MnCl)Mn_4(SiO_4)_4$.	Rose-red.	Vitreous.	C. Basal, *per.*	4–5	3.07	4	Hexag.
	Fuses quietly to a black glass.	Bementite.	H_2MnSiO_4? Fe, Mg, & Zn iso. w. Mn	Pale grayish-yellow	Pearly.	C. Basal, *per.*	2.5–3	2.98	3.5	Foliated.
	Splits apart and often crumbles when first heated B. B.	Inesite.	$3(Mn,Ca)SiO_3.2H_2O$.	Rose- to flesh-red.	Vitreous.	C. Pinac., *per.* F. Uneven.	6	3.03	3	Triclinic.

DIVISION 4, *Section a.*—Concluded on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 4.—Decomposed by hydrochloric acid, *with the separation of silica,* but without the formation of a jelly.

Section b.—In the closed tube give little or no water.

DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.—In part.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

Part III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic*.

Division 4.—Decomposed by hydrochloric acid, *with the separation of silica*, but without the formation of a jelly.

Section b.—In the closed tube give little or no water.—Anhydrous silicates.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Insoluble in HCl, and yet sufficiently decomposed to give a violet color (*titanium*) when the partial solution is boiled with tin (p. 127. § 2).		**TITANITE.** (Sphene.)	$CaTiSiO_5$.	Gray, brown, green, yellow.	Resinous, adamantine.	C. Prismatic. F. Uneven.	5–5.5	3.4–3.55	4	Monocl. Page 213.
With borax in O. F. gives a reddish-violet bead (*Mn*).	Fuses with difficulty to a black slag. Crystals are apparently hexagonal.	Trimerite.	$Be(Mn,Ca,Fe)SiO_4$.	Salmon-pink to colorless.	Vitreous.	C. Basal. F. Uneven.	6–7	3.47	4–5?	Triclinic.
Fuses quietly to a white, almost glassy globule. Rather easily decomposed by HCl.	After decomposition with HCl and separation of the silica, ammonia produces little or no precipitate. To detect calcium, see p. 60, § 6.	**WOLLASTONITE.**	$CaSiO_3$.	White, gray, colorless.	Vitreous, pearly.	C. Pinac., *per.* F. Uneven.	5–5.5	2.8–2.9	4	Monocl.
Fuses quietly to a glassy globule. Slowly acted upon by HCl. See *The Feldspars* (p. 285).	Usually shows striations on the best cleavage surface. Often exhibits a brilliant play of colors.	**LABRADORITE.** (Lime-soda Feldspar.)	$3CaAl_2Si_2O_8$. $NaAlSi_3O_8$.	White, gray, brown, green.	Vitreous.	C. Basal, *per.*, & pinacoidal F. Uneven.	5–6	2.73	4–4.5	Triclinic. U. mass.
Fuse with intumescence to a vesicular glass. Wernerite is slowly acted upon by HCl.	Wernerite gives during fusion a strong yellow flame (*sodium chloride*); Meionite contains no, or only a very little, chlorine. Test as directed on p. 67, § 1.	**WERNERITE.** (Scapolite.)	$Ca_4Al_6Si_6O_{25}$. $Na_4Al_3Si_9O_{24}Cl$.	White, gray, light-green.	Vitreous.	C. Prismatic. F. Uneven.	5–6	2.68	3	Tetrag. Page 183.
		Meionite.	$Ca_4Al_6Si_6O_{25}$.	Colorless to white	Vitreous.	C. Prismatic. F. Uneven.	5.5–6	2.74	4	Tetrag. Cl. 20, p. 219.

Division 5.—Not belonging to the foregoing divisions.—*Insoluble in hydrochloric acid*, or only slightly acted upon.

N.B.—The minerals in this division, with the exception of a few placed at the beginning, are *silicates*. This may be proved by fusing with sodium carbonate, and then obtaining *gelatinous silica* by treating the fused material with nitric acid and evaporating, as directed on p. 110, § 4. There are also given on pp. 111 and 112 some simple methods for the detection of the bases which most often occur, namely, *aluminium*, *ferric* and *ferrous iron*, *calcium* and *magnesium*. The flame tests B. B., or made as directed on p. 105, § 1, *c*, serve for the detection of *sodium* and *potassium*.—A number of the silicates in this division, after fusion, dissolve in HCl and yield gelatinous silica on evaporation. To try the experiment pulverize some particles which have been thoroughly fused B. B., and treat the powder as directed on p. 278, Division 3.—A careful determination of the *crystallization*, *cleavage*, *specific gravity* and *hardness* will be found most useful for the identification and recognition of these silicates, which, as a rule, do not give very pronounced blowpipe reactions.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Phosphates.—After fusion with Na_2CO_3 and dissolving in HNO_3, a little of the solution will give a yellow precipitate when added to ammonium molybdate (p. 102, § 1). The pale *bluish-green* flame coloration, often seen best after moistening the assay with H_2SO_4, may be employed for the identification of a phosphate.	B. B. generally give a red flame (*lithium*), but the color may be obscured by sodium. Give a reaction for fluorine (p. 76, § 2). Montebrasite gives acid water in the closed tube (p. 77, § 5).	**Amblygonite.**	$Li(AlF)PO_4$. Na iso. w. Li.	White to pale-green or blue.	Vitreous to greasy.	C. Basal, *per.* F. Uneven.	6	3.08	2	Triclinic. U. mass.
		Montebrasite.	$Li[Al(OH,F)]PO_4$. Na iso. w. Li.	White to pale-green or blue	Vitreous to greasy.	C. Basal, *per.* F. Uneven.	6	3.00	2	Triclinic. U. mass
	After fusion with Na_2CO_3 and dissolving in HCl, the solution gives a precipitate with H_2SO_4 (p. 53, § 3, *b*).	Hamlinite.	$(Sr.OH)(Al.2OH)_3P_2O_7$. Ba iso. w. Sr; F iso. w. OH	White to yellowish-white.	Pearly, greasy.	C. Basal, *per.*	4.5	3.15–3.25	4	Hex. Rh.
	Fuse to a white enamel. Herderite gives strongly acid water in the closed tube (p. 77, § 5). Hydro-herderite and Cirrolite give neutral or only slightly acid water. To prove the presence of beryllium, see p. 54, § *b*.	**Herderite.**	$Ca[Be(F,OH)]PO_4$.	White to pale-green or yellow	Vitreous, resinous.	F. Uneven.	5	3.00	4	Monocl.
		Hydro-herderite.	$Ca(Be.OH)PO_4$.	White to pale-green or yellow	Vitreous, resinous.	F. Uneven.	5	2.95	4	Monocl.
		Cirrolite.	$(Ca.OH)_3Al_2(PO_4)_3$.	White to pale-yellow.	Vitreous.	F. Uneven.	5–6	3.08	4	Massive.
Tungstates. — Decomposed by boiling HCl, leaving a yellow residue of *tungstic oxide* (p. 128, § 1). It is best to treat Hübnerite as directed on p. 129, § 2. Note the high Sp. Gr.	Imparts to the borax bead in O. F. a reddish-violet color (*manganese*).	**Hubnerite.** See *wolframite*, p. 254.	$MnWO_4$. Fe iso. w. Mn.	Brown to brown-black.	Resinous.	C. Pinac., *per.* F. Uneven.	5–5.5	7.2	4	Monocl.
	In the dilute HCl solution, made alkaline with ammonia, test for *calcium* with ammonium oxalate (p. 60, § 6).	**Scheelite.**	$CaWO_4$.	White, yellow, green, brown.	Vitreous, adamantine.	C. Pyramidal. F. Uneven.	4.5–5	6.05	5	Tetrag. Page 182.
Fluoride.—Heated in a bulb tube with potassium bisulphate give a deposit of silica and vapors which corrode the glass (p. 76, § 2).		**Sellaite.**	MgF_2.	Colorless to white.	Vitreous.	C. Basal, *per.* F. Conchoidal.	5	2.95–3.10	4–5?	Tetrag.

Division 5.—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic*.

DIVISION 4.—Decomposed by hydrochloric acid *with the separation of silica*, but without the formation of a jelly.

Section a.—In the closed tube give water.—Concluded.

B.—Fusible from 1–5, and Non-volatile, or only Slowly or Partially Volatile.

Part III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

Division 4.—Decomposed by hydrochloric acid *with the separation of silica,* but without the formation of a jelly.

Section a.—In the closed tube give water.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain *calcium,* but no *aluminium.*—After decomposing with HCl and separation of the silica, ammonia produces little or no precipitate, but ammonium carbonate precipitates *calcium carbonate* (p. 60, § 5).	Fuses quietly to a glass coloring the flame yellow (*sodium*). 3% H_2O.	**Pectolite.**	$HNaCa_2(SiO_3)_3$.	Colorless, white, gray.	Vitreous, pearly.	C. Pinac., *per.* F. Splintery.	5	2.7–2.8	2.5–3	Monocl. Fig. 361, page 222.
	Fuses with swelling to a white, vesicular enamel. Colors the flame pale violet (*potassium*). 16% H_2O.	**APOPHYLLITE.**	$H_7KCa_4(SiO_3)_8.4\frac{1}{2}H_2O$. (NH_4) & F in traces.	White, pale-green, yellow, rose.	Pearly, vitreous.	C. Basal, *per.* F. Uneven.	4.5–5	2.3–2.4	2	Tetrag. Page 181.
B. B. at first becomes opaque and then fuses quietly to a clear glass. Colors the flame yellow.	Usually crystallizes in trapezohedrons (Fig. 105, p. 171), sometimes in combination with the cube (Fig. 107).	**ANALCITE.**	$NaAl(SiO_3)_2.H_2O$.	Colorless or white.	Vitreous.	F. Uneven.	5–5.5	2.27	3.5	Isometric.
Gives little water in the closed tube. Fuses with intumescence to a swollen, blebby enamel.	Decomposed slowly and with difficulty by HCl.	**PREHNITE.**	$H_2Ca_2Al_2(SiO_4)_3$. Fe iso. w. Al.	Apple-green, gray, white.	Vitreous.	F. Uneven.	6–6.5	2.90	2.5	Orthorh. Reniform.
Give much water in the closed tube. Generally fuse with swelling and intumescence.—After decomposing with HCl and separation of the silica, ammonia produces a precipitate of *aluminium hydroxide,* and in the filtrate ammonium carbonate gives a precipitate of *calcium, barium* or *strontium carbonates.* Many of these silicates are closely related in chemical composition, and differences in crystallization must be relied upon for their identification. Harmotome, Wellsite, and Phillipsite generally occur in complex, twin crystals, often resembling tetragonal prisms, terminated by pyramids of the opposite order.	Contain *barium.*—The dilute HCl solution gives with dilute H_2SO_4 a precipitate of *barium sulphate.* B. B. Brewsterite exfoliates prodigiously before fusing; Wellsite and Harmotome whiten and then fuse.	Brewsterite.	$H_4(Sr,Ba,Ca)Al_2(SiO_3)_6.3H_2O$.	White, yellow, gray.	Vitreous, pearly.	C. Pinac., *per.* F. Uneven.	5	2.45	3	Monocl.
		Wellsite.	$(Ca,K_2,Ba)Al_2Si_3O_{10}.3H_2O$.	White or colorless.	Vitreous.	F. Uneven.	4–4.5	2.3–2.35	3	Monocl. Twinned.
		Harmotome.	$(Ba,K_2)Al_2Si_5O_{14}.5H_2O$.	White or colorless.	Vitreous.	C. Pinacoidal. F. Uneven.	4.5	2.4–2.5	3	Monocl. Twinned.
	Hexagonal, rhombohedral. B.B. fuse with swelling. Gmelenite often cracks and splits apart before fusion.	**CHABAZITE.** (Phacolite.)	Approx. $(Ca,Na_2)Al_2(SiO_3)_4.6H_2O$	White, yellow, flesh-red.	Vitreous.	C. Rhombohed. F. Uneven.	4–5	2.05–2.15	3	Hex. Rh. Page 195.
		Gmelenite.	Approx. $(Na_2.Ca)Al_2(SiO_3)_4.6H_2O$.	White, yellow, flesh-red.	Vitreous.	C. Prismatic. F. Uneven.	4.5	2.05–2.15	3	Hex. Rh.
	Fuse with swelling and intumescence. Stilbite is commonly in sheaf-like aggregations of crystals, or radiated; isolated crystals, owing to twinning, have an orthorhombic aspect. On Heulandite the pinacoid faces with pearly luster are usually lozenge-shaped.	**STILBITE.** (Desmine.)	$H_4(Ca,Na_2)Al_2(SiO_3)_6.4H_2O$.	White, yellow, brown, red.	Pearly, vitreous.	C. Pinac., *per.* F. Uneven.	3.5–4	2.1–2.2	3	Monocl. Twinned.
		HEULANDITE.	$H_4(Ca,Na_2)Al_2(SiO_3)_6.3H_2O$.	White, yellow, red.	Pearly, vitreous.	C. Pinac., *per.* F. Uneven.	3.5–4	2.15–2.2	3	Monocl.
		Epistilbite.	$H_4(Ca,Na_2)Al_2(SiO_3)_6.3H_2O$.	White.	Pearly, vitreous.	C. Pinac., *per.* F. Uneven.	4–4.5	2.2–2.25	3	Monocl. Twinned.
	B. B. Whitens and fuses without swelling to a vesicular enamel. Reacts for potassium (p. 105, § 1, *c*).	**Phillipsite.**	$(Ca,K_2,Na_2)Al_2Si_4O_{12}.4H_2O$.	White.	Vitreous.	C. Pinacoidal. F. Uneven.	4.5–5	2.2	3	Monocl. Twinned.
	Crystallizes in octahedrons.	**Faujasite.**	$H_2(Ca,Na_2)Al_2(SiO_3)_5.9H_2O$.	White to brown.	Vitreous.	C. Octahedral. F. Uneven.	5	1.92	3	Isometric.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

Part III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

Division 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.—Continued.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.—Continued.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
THE MICAS, and minerals with *foliated structure.**—These minerals possess such a remarkable cleavage that they can be split into exceedingly thin sheets. Sometimes they occur as aggregates of minute scales, and then the micaceous structure is not so apparent. Distinct crystals usually have a hexagonal and sometimes an orthorhombic aspect. The true micas give only a little water when intensely ignited B. B. in a closed glass tube, and their foliæ are tough and elastic. ☞ Compare *Lepidomelane* (p. 269) and *Vermiculite* (p. 281).	Give a red flame when heated B. B. (*lithium*).	Easily fusible to a white or gray globule. Gives acid water when intensely ignited in a closed tube (p. 77, § 5).	**LEPIDOLITE.** (Lithia Mica.)	$LiK[Al(OH,F)_2]Al(SiO_3)_3$.	Lilac, grayish-white.	Pearly.	C. Basal, *per.*	2.5–4	2.8–2.9	2	Monocl. U. gran.
		Easily fusible to a dark-colored globule. See p. 270.	Zinnwaldite.	$(K,Li)_3Fe''(AlO)(AlF_2)Al(SiO_3)_5$. OH iso. w. F.	Gray, brown, violet.	Pearly.	C. Basal, *per.*	2.5–3	2.8–3.2	2.5–3	Monocl.
		B. B. exfoliates prodigiously, and fuses with difficulty. Gives much water in the closed tube.	**Cookeite.**	$Li(Al.2OH)_3(SiO_3)_2$.	White.	Pearly.	C. Basal, *per.*	2.5	2.67	4.5–5	Monocl. U. radiat.
	Scarcely acted upon by boiling concentrated H_2SO_4.—This test should be made as follows: cleave out a few exceedingly thin scales of the mineral and boil them in a test-tube with 3 c.c. of acid for about a minute. The mica scales should preserve their luster and transparency when thus treated, and the acid should not become turbid nor milky. *Never attempt to add water, or to clean out the test-tube until the acid* (*boiling point* 338° C.) *has become cold.*	Light-colored mica. Found usually with quartz and feldspar.	**MUSCOVITE.** (Common or Potash Mica.)	$H_2KAl_3(SiO_4)_3$. Fe iso. w. Al.	Pale-brown, -green, -yellow, white.	Vitreous, pearly.	C. Basal, *per.*	2–2.5	2.86	4.5–5	Monocl.
		Imparts a green color to the borax bead in R. F. (*chromium*).	Fuchsite. (Chrome Mica.)	$H_2K(Al,Cr)_3(SiO_4)_3$	Emerald-green	Vitreous, pearly.	C. Basal, *per.*	2–2.5	2.86	5	Monocl.
		Imparts a yellow color to the blowpipe flame (*sodium*).	Paragonite. (Soda Mica.)	$H_2NaAl_3(SiO_4)_3$.	Yellowish- to grayish-white.	Pearly.	C. Basal, *per.*	2.5–3	2.89	5	Monocl. U. gran.
		B. B. easily fusible. Gives a faint violet flame (*potassium*).	Alurgite.	$H(K,Mg.OH)_2(Al.OH)Al(SiO_3)_4$. Mn iso. w. Al.	Rose-red to deep-red.	Pearly.	C. Basal, *per.*	3	2.84	3	Monocl.
		Soft, and has a *greasy feel.* Foliæ flexible, but not elastic.	**TALC.** (Steatite, Soapstone.)	$H_2Mg_3(SiO_3)_4$.	Apple-green, gray, white.	Pearly, greasy.	C. Basal, *per.*	1	2.80	5	Foliated, compact.
		Harder than the true micas. Foliæ rather brittle.	**Margarite.** (Brittle Mica.)	$H_2CaAl_4Si_2O_{12}$.	Pink, gray, white.	Pearly.	C. Basal, *per.*	3.5–4.5	3.05	4–4.5	Monocl.
		☞ Compare *Biotite, Clinochlore* and *Kämmererite* below, which are slowly decomposed by H_2SO_4.									
	Decomposed by boiling, concentrated H_2SO_4, when treated as directed in the foregoing paragraph, that is, the thin scales lose their luster and transparency, and the acid becomes turbid or milky. ☞ Phlogopite is much more readily decomposed than biotite. Margarite of the foregoing section is slowly acted upon by boiling H_2SO_4.	Usually a dark-colored mica. Found in veins with quartz and feldspar, and very common in eruptive rocks.	**BIOTITE.** (Common dark-green or black Mica.)	$(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$	Green, yellow, brown, black.	Splendent.	C. Basal, *per.*	2.5–3	2.95–3.0	5	Monocl.
		Usually a light-, though sometimes a dark-colored, mica. Found in crystalline limestone. Almost always contains about 3 per cent of fluorine (p. 77, § 4).	**PHLOGOPITE.** (Magnesia Mica.)	$(H,K)_3(Mg,Fe)_3(Al,Fe)(SiO_4)_3$. F iso. w. OH.	Yellowish-brown, green, white.	Vitreous, pearly.	C. Basal, *per.*	2.5–3	2.86	4.5–5	Monocl. Triclinic.
		Foliæ *flexible,* but not *elastic.* Give much water in the closed tube, but only when intensely ignited B. B. Penninite has apparently a hexagonal-rhombohedral crystallization which results from twinning.	**CLINOCHLORE. PENNINITE.** (Ripidolite, Chlorite.)	$H_8Mg_5Al_2Si_3O_{18}$. Fe iso. w. Mg & Al.	Green of various shades. Rarely white.	Vitreous, pearly.	C. Basal, *per.*	2–2.5	2.65–2.75	5–5.5	Monocl.
		Color *reddish.* Imparts to the borax bead in R. F. a green color (*chromium*). Otherwise like Clinochlore.	**Kämmererite.** (Chrom Clinochlore.)	$H_8Mg_5(Al,Cr)_2Si_3O_{18}$.	Garnet- to peach-blossom-red.	Vitreous, pearly.	C. Basal, *per.*	2–2.5	2.65–2.75	5–5.5	Monocl.
		Gives with salt of phosphorus in O. F. a yellow, and in R. F. a green, bead (*vanadium*).	Roscoelite.	$H_8K_2(Mg,Fe)(Al,V)_4(SiO_3)_{12}$?	Clove-brown, brownish-green.	Pearly.	C. Basal, *per.*	2?	2.93	3?	Scales.

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* It is a difficult matter to pulverize mica. The material, however, may be obtained in sufficiently fine condition for the foregoing tests by scraping with a knife-blade, or cleaving into exceedingly thin sheets, and breaking or cutting them up.

DIVISION 5.—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 5 —*Insoluble in hydrochloric acid,* or only slightly acted upon.—Continued.

II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic*.

DIVISION 5.—*Insoluble in hydrochloric acid*, or only slighly acted upon.—Continued.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
THE FELDSPARS.—Characterized by two good cleavages at 90° or nearly 90°, light color, difficult fusibility, hardness about 6, and specific gravity ranging from 2.55 to 2.80.	Contains *barium*, which may be detected as described on p. 53, § 3, *b*.	Hyalophane. (Barium Feldspar.)	$KAlSi_3O_8$. $BaAl_2Si_2O_8$	Colorless, white.	Vitreous.	C. Basal, *per.*, pinac., ∠ 90°.	6–6.5	2.80	5	Monocl.
	Give the reaction for *potassium* when mixed with gypsum, and heated on platinum wire (p. 105, § 1, *c*). Microcline may exhibit on its cleavage or crystal faces a system of fine striations, indicating a complex twinning structure, but generally it is impossible to distinguish between Microcline and Orthoclase except by their different action on polarized light. Sanidine and Anorthoclase are feldspars found in eruptive rocks, which give decided reactions for both sodium and potassium.	**ORTHOCLASE.** (Potash Feldspar.)	$KAlSi_3O_8$. Na iso. w. K.	Colorless, white, cream, flesh-red, gray, green.	Vitreous, pearly.	C. Basal, *per.*, pinac., ∠ 90°.	6	2.57	5	Monocl. Page 211.
		MICROCLINE.	$KAlSi_3O_8$. Na iso. w. K.	White, cream, red, green.	Vitreous, pearly.	C. Basal, *per.*, pinacoidal, ∠ 89° 30′	6	2.57	5	Triclinic.
		Sanidine.	$(K,Na)AlSi_3O_8$.	Colorless, white, gray.	Vitreous, pearly.	C. Basal, *per.*, pinac., ∠ 90°.	6	2.57	4–4.5	Monocl.
		Anorthoclase.	$(Na,K)AlSi_3O_8$.	Colorless, white, gray.	Vitreous, pearly.	C. Basal, *per.*, pinacoidal, ∠ 89°–90°.	6	2.59	4–4.5	Triclinic.
	Give a strong yellow flame (*sodium*), and but little or no reaction for potassium when mixed with gypsum, and heated on platinum wire as directed on p. 105, § 1, *c*.—Generally on the basal or best cleavage surface a system of fine parallel striations may be detected which reveal the presence of a complex twinning structure (Fig. 87, p. 168). These minerals, often called the *Plagioclase Feldspars*, form chemically a continuous series from Albite $NaAlSi_3O_8$ to Anorthite $CaAl_2Si_2O_8$. They can scarcely be distinguished from one-another by their blowpipe reactions, but a test for calcium, made as directed on p. 110, § 4, may help in the identification. Labradorite is very slowly acted upon by acids. Anorthite dissolves slowly and yields gelatinous silica (p. 280).	**ALBITE.** (Soda Feldspar.)	$NaAlSi_3O_8$.	Colorless, white, gray.	Vitreous, pearly.	C. Basal, *per.*, pinacoidal, ∠ 86° 24′.	6	2.62	4–4.5	Triclinic, Page 216.
		OLIGOCLASE. (Soda-lime Feldspar.)	$3NaAlSi_3O_8$. $1CaAl_2Si_2O_8$.	Colorless, white, gray, greenish, bluish, reddish. Often exhibit a beautiful play of colors on the pinacoid face (010).	Vitreous, pearly.	C. Basal, *per.*, pinacoidal, ∠ 86° 32′	6	2.66	4–4.5	Triclinic. U. mass.
		ANDESITE. (Lime-soda Feldspar.)	$1NaAlSi_3O_8$. $1CaAl_2Si_2O_8$.		Vitreous, pearly.	C. Basal, *per.*, pinacoidal, ∠ 86° 14′	6	2.69	4–4.5	Triclinic. U. mass.
		LABRADORITE. (Soda-lime Feldspar.)	$1NaAlSi_3O_8$. $3CaAl_2Si_2O_8$.		Vitreous, pearly.	C. Basal, *per.*, pinacoidal, ∠ 86° 4′.	6	2.73	4–4.5	Triclinic. U. mass.
		ANORTHITE. (Lime Feldspar.)	$CaAl_2Si_2O_8$.	Colorless, white, gray.	Vitreous, pearly.	C. Basal, *per.*, pinacoidal, ∠ 85° 50′.	6	2.75	4.5	Triclinic.
Color the blowpipe flame green (*boron*). ☞ Compare *Boracite* (p. 277) which is slowly soluble in HCl, also *Axinite*, below.	Gives no water in the closed tube.	**Danburite.**	$CaB_2(SiO_4)_2$.	White to pale yellow	Vitreous.	F. Uneven.	7	3.0	3.5–4	Orthorh.
	Gives abundant water in the closed tube.	Howlite.	$H_5Ca_2B_5SiO_{14}$.	White.	Vitreous.	Splintery.	3.5	2.59	2	Nodular, fibrous.
When mixed with potassium bisulphate and fluorite and heated on platinum wire, momentarily color the flame green (*boron*, p. 56, § 1).	B. B. fuses with swelling and bubbling. May impart a faint green color to the flame.	**Axinite.**	$R_7Al_4B_2(SiO_4)_8$. R=Ca, Mn, Fe, Mg, Zn and a little H_2.	Clove-brown, gray, green, yellow.	Vitreous.	C. Pinacoidal. F. Conchoidal.	6.5–7	3.27–3.35	2.5–3	Triclinic. Page 216.
	B. B. fuses with swelling and bubbling, sometimes to a globule, sometimes to a slaggy mass. Exhibits pyroelectricity (p. 231), which succeeds best with light colored varieties.	**TOURMALINE.** See p. 300.	$R'_9Al_3(B.OH)_2Si_4O_{19}$. R'_9 replaced by Al, Fe'', Mg, Mn, Ca, Na, K, Li & H. F iso. w. OH.	Black, brown, green, blue, red, pink, white	Vitreous.	F. Conchoidal, Uneven.	7–7.5	3.0–3.15	3–5 U.3.	Hex. Rh. Hemimor. Page 195.
Color the blowpipe flame red (*lithium*), which is at times obscured by sodium (p. 90). ☞ Compare the phosphates and micas, this division.	B. B. usually throws out fine branches when first heated, and then fuses to a clear glass.	**SPODUMENE.** (When green, Hiddenite.)	$(Li,Na)Al(SiO_3)_2$.	White, gray, pink, emerald-green.	Vitreous.	C. Prism., *per.* F. Uneven.	6.5–7	3.18	3.5	Monocl. U. prism.
	Fuses quietly to a white enamel.	**Petalite.**	$(Li,Na)Al(Si_2O_5)_2$.	White, gray, pink.	Vitreous, pearly.	C. Basal, *per.* F. Uneven.	6–6.5	2.40	4	Monocl. U. mass.

DIVISION 2.—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.—Continued.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 5.—*Insoluble in hydrochloric acid*, or only slightly acted upon.—Continued.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Contain *manganese.*—Impart to the borax bead in O. F. a reddish-violet color, which becomes colorless in R. F.	Gives much water in the closed tube.	Carpholite.	$Mn(Al.2OH)_2(SiO_3)_2$.	Straw-yellow, wax-yellow.	Silky.	F. Splintery.	5–5.5	2.93	3	Monocl. U. fibrous
	Characterized by its isometric crystallization. Gelatinizes with HCl after fusion.	**SPESSARTITE.** (Manganese Garnet.)	$(Mn,Fe,Ca)_3(Al,Fe)_2(SiO_4)_3$.	Brownish- to garnet-red.	Vitreous.	F. Uneven to Conchoidal.	7–7.5	4.2	3	Isometric. U. cryst.
	Like the foregoing, but with monoclinic crystallization.	Partschinite.	$(Mn,Fe)_3Al_2(SiO_4)_3$	Yellowish, reddish.	Greasy.	F. Uneven.	6.5–7	4.0	3	Monocl.
	Distinctly cleavable in two directions at 92°–93°. Do not gelatinize with HCl after fusion. Rhodonite fuses to an almost black, and Schefferite to a brownish glass. Fowlerite and Jeffersonite when fused on charcoal with a little Na_2CO_3 in R. F. give a slight coating of *oxide of zinc.*	**RHODONITE.**	$MnSiO_3$. Fe and Ca iso. w. Mn.	Rose-red, pink, brown.	Vitreous.	C. Prism., *per.* F. Uneven	6–6.5	3.63	3–3.5	Triclinic. Page 217.
		Fowlerite. (Zinc Rhodonite.)	$(Mn,Zn,Fe,Ca,Mg)SiO_3$.	Rose-red.	Vitreous.	C. Prism., *per.* F. Uneven.	6–6.5	3.67	3–3.5	Triclinic. Page 217.
		Schefferite. (Manganese Pyroxene.)	$(Ca,Mn)(Mg,Fe)(SiO_3)_2$.	Yellowish- to reddish-brown	Vitreous.	C. Prismatic. F. Uneven.	5–6	3.5	4	Monocl.
		Jeffersonite. (Manganese-zinc Pyroxene.)	$(Ca,Mn)(Mg,Fe,Zn)(SiO_3)_2$.	Greenish-black to brown.	Vitreous.	C. Prismatic. F. Uneven.	5–6	3.6	4	Monocl.
	Characterized by a perfect prismatic cleavage, at angles of 55° and 125°.	Richterite. (Manganese Amphibole.)	$(Mg,Mn,Ca,Na_2)_4(SiO_3)_4$.	Brown, yellow, rose-red.	Vitreous.	C. Prism., *per.* F. Uneven.	5.5–6	3.09	4	Monocl. Prismatic.
	Give a reaction for vanadium (p. 130, § 2) and sometimes for arsenic (p. 51, § 1, *c*).	Ardennite.	$H_5Mn_4Al_4V.Si_4O_{23}$? As iso. w. V.	Yellow to yellowish-brown.	Resinous.	C. Pinac., *per.* F. Uneven.	6–7	3.65	2–2.5	Orthorh.
	Fuses with much effervescence to a black glass.	**Piedmontite.** (Manganese Epidote.)	$Ca_2(Al.OH)(Al,Mn,Fe)_2(SiO_4)_3$.	Reddish-brown, reddish-black.	Vitreous.	C. Basal., *per.* F. Uneven.	6.5	3.5	3	Monocl.
Contain *titanium.*—Fused with Na_2CO_3, then dissolved in HCl and boiled with tin the solution becomes violet (p. 127, § 2).	Fuse with slight intumescence to a dark mass.	**TITANITE.** (Sphene.)	$CaTiSiO_5$.	Gray, brown, green, yellow, black.	Resinous, adamantine.	C. Prismatic. F. Uneven.	5–5.5	3.4–3.55	4	Monocl. Page 213.
		Guarinite.	$CaTiSiO_5$.	Sulphur- to honey-yellow.	Adamantine.	C. Pinacoidal. F. Uneven.	6	3.49	4	Orthorh. Tabular.
	Very similar to Titanite. Gives reactions for *yttrium* (p. 65).	Keilhauite.	$\left\{ \begin{array}{l} CaTiSiO_5 \\ (Y,Al,Fe)_2SiO_5. \end{array} \right.$	Brownish-black.	Vitreous, resinous.	C. Prismatic. F. Uneven.	6.5	3.5–3.7	4–4.5	Monocl.
	Easily fusible to a black globule.	Neptunite.	$(Na,K)(Fe,Mn)TiSi_4O_{12}$	Black.	Vitreous.	C. Prismatic. F. Uneven.	5–6	3.23	3.5	Monocl.
Contain *water of crystallization.*—In the closed tube, at a low temperature, give much water. A number of the silicates beyond contain *hydroxyl*, and on intense ignition in the closed tube, yield water (p. 81, § 1, *b*). ☞ Compare *Prehnite*, *Lawsonite*, *Euclase*, *Talc*, and others.	After boiling with HCl and filtering, the solution gives a precipitate with H_2SO_4 (*barium*). See p. 282.	**Harmotome.**	$(Ba,K_2)Al_2Si_5O_{14}.5H_2O$.	White, colorless.	Vitreous.	C. Pinacoidal. F. Uneven.	4.5	2.4–2.5	3	Monocl. Twinned.
	Fuses quietly. Crystallizes in six-sided prisms.	**Offretite.**	$(K_2,Ca)_2Al_6Si_{14}O_{39}.17H_2O$.	White, colorless.	Vitreous.	C. Prismatic.		2.13	3	Hexag. Tabular.
	Occurs in very fine capillary crystals.	**Ptilolite.**	$(Ca,K_2,Na_2)Al_2Si_{10}O_{24}.5H_2O$.	White.	Vitreous.				4–5	Capillary.
	Occurs in tabular crystals resembling heulandite, and in radiated groups.	**Mordenite.**	$(K_2,Na_2.Ca)Al_2Si_{10}O_{24}.6\frac{2}{3}H_2O$.	White, yellow, pinkish.	Vitreous, pearly.	C. Pinac., *per.* F. Uneven.	3–4	2.1–2.15	4–5	Monocl.

DIVISION 5.—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule*, and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 5.—*Insoluble in hydrochloric acid*, or only slightly acted upon.—Continued.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.—Continued.

The remaining silicates in this division are arranged according to their crystallization, because there are no sufficiently pronounced blowpipe characters which may be used for subdividing them into groups. When crystals are not at hand the species in almost all cases may be identified readily by their blowpipe and physical properties, as given in the table.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
Fuse quietly. Gelatinize with HCl after fusion.—To distinguish with certainty between Grossularite and Pyrope, tests in the wet way for calcium and magnesium must be made.	Generally crystallize in dodecahedrons and trapezohedrons or their combination, Figs. 97, 105, and 106 (pp. 170–172). ☞ Compare the different varieties of **GARNET**, *Almandite* (p. 270), *Andradite* (p. 269), *Spessartite* (p. 286), and *Uvarovite* (p. 299).	**GROSSULARITE.** (Calcium-aluminium Garnet.)	$Ca_3Al_2(SiO_4)_3$. Fe, Mg, & Mn iso. w. Ca. Fe iso. w. Al.	Pale-red, yellow, green, white.	Vitreous.	F. Uneven to Conchoidal.	6.5–7.5	3.5–3.6	3	Isometric.
		PYROPE. (Magnesium-aluminium Garnet.)	$(Mg,Fe,Ca)_3Al_2(SiO_4)_3$. Fe and Cr iso. w. Al.	Deep-red, rarely amethystine.	Vitreous.	F. Uneven to Conchoidal.	6.5–7.5	3.6–3.7	3.5–4	Isometric.
Fuses with intumescence to a greenish or brownish glass.	Gelatinizes with HCl after fusion.	**VESUVIANITE.** (Idocrase.)	$Ca_6[Al(OH,F)](Al,Fe)_2(SiO_4)_5$. Mg, Fe & Mn iso. w. Ca.	Green, brown, yellow, blue, red.	Vitreous, resinous.	F. Uneven.	6.5	3.35–3.45	3	Tetrag. Page 180
Fuse with intumescence to a white mass. Color the flame intensely yellow (*sodium chloride*).	Minerals of the **SCAPOLITE GROUP.** Compare *Meionite* (p. 283). Wernerite is slowly acted upon by HCl. Test for chlorine, after fusion with Na_2CO_3, as directed on p. 67, § 1.	**WERNERITE.** (Scapolite.)	$Ca_4Al_6Si_6O_{25}$. $Na_4Al_3Si_9O_{24}Cl$.	White, gray, light-green.	Vitreous.	C. Prismatic. F. Uneven.	5–6	2.68	3	Tetrag. Page 183
		Marialite.	$Na_4Al_3Si_9O_{24}Cl$.	Colorless, white.	Vitreous.		5.5–6	2.56	3–4	Tetrag. Cl. 20, p. 219.
Fuses with intumescence to a white blebby glass.	B. B. in the closed tube whitens, and gives a little water at a high temperature.	Milarite.	$HKCa_2Al_2(Si_2O_5)_6$.	Colorless to pale-green.	Vitreous.	F. Conchoidal.	5.5–6	2.55	3	Hexag.
B. B. whitens, and fuses at 5 to 5½ to an enamel. Yields a little water on *intense ignition.*	The varieties of beryl containing alkalies (Na, Li, Cs) are more fusible than those without. See p. 300.	**BERYL.** (Aquamarine when pale-green; Emerald when deep-green.)	Approximately $Be_3Al_2(SiO_3)_6.\frac{1}{2}H_2O$ Na_2, Li_2 & Cs_2 iso. w. Be.	Green, blue, yellow, pink, colorless.	Vitreous.	F. Conchoidal, Uneven.	7.5–8	2.75–2.8	5–5.5	Hexag. Page 188
Fuses quietly. Colors the flame intensely yellow (*sodium*).	Generally phosphoresces when heated (p. 231). Gives a slight reaction for fluorine (p. 76, § 3).	Leucophanite.	$Na(BeF)Ca(SiO_3)_2$.	Pale-green, yellow, white.	Vitreous.	C. Basal, *per.* F. Conchoidal.	4	2.96	2.5–3	Orthorh. Cl. 27, p. 219.
Fuses quietly and with difficulty.	Yields 1½ per cent of water on *intense ignition* of the powdered mineral in the closed tube.	**IOLITE.** (Cordierite.)	$H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$.	Blue, rarely colorless.	Vitreous.	C. Pinacoidal. F. Conchoidal.	7–7.5	2.60	5–5.5	Orthorh.
Fuses with swelling and intumescence to an enamel.	Loses 4.5% of water on ignition. Slowly acted upon by HCl, but gelatinizes after fusion.	**PREHNITE.**	$H_2Ca_2Al_2(SiO_4)_3$. Fe iso. w. Al.	Apple-green, gray, white.	Vitreous.	F. Uneven.	6–6.5	2.9	2.5	Orthorh. Reniform.
B. B. cracks open, swells, and fuses to a frothy mass.	Yields 11 per cent of water on intense ignition in the closed tube.	Lawsonite.	$Ca(Al.2OH)(SiO_3)_2$.	Grayish-blue to white.	Vitreous.	C. Pinac., *per.* F. Uneven.	8	3.09	4	Orthorh.
Fuses with intumescence, coloring the flame yellow (*sodium*).	Gives 3½ per cent of water on intense ignition in the closed tube.	Epididymite. See *eudidymite*, p. 288.	$HNaBeSi_3O_8$.	Colorless.	Vitreous, pearly.	C. Basal, *per.*	6	2.55	2.5–3	Orthorh.
Very difficultly fusible. Fus. = 5–6. ☞ These minerals are the orthorhombic representatives of the Amphibole and Pyroxene groups, respectively. See p. 288.	Characterized by its perfect prismatic cleavage, at angles of 54° and 126°. Sometimes fibrous (*asbestiform*).	Anthophyllite. (Asbestus, in part.)	$(Mg,Fe)SiO_3$. H_2 iso. w. Mg.	Gray, clove-brown, green.	Vitreous, pearly.	C. Prism., *per.*	5.5–6	3.10	5–6	Orthorh. U. prism.
	Has a prismatic cleavage (less perfect than the foregoing) at angles of 88° and 92°.	**ENSTATITE.** (Bronzite).	$(Mg,Fe)SiO_3$.	Gray brown, green.	Pearly, bronze-like.	C. Prismatic. F. Splintery.	5.5–6.5	3.2–3.3	5–6	Orthorh. U. mass.
Fuse with swelling and intumescence to a slaggy mass, which, on continued heating, does not readily melt to a globule. Gelatinize with HCl after fusion.	Fuse to a light-colored slag. Yield about 2 per cent of water on very *intense ignition* of the *powdered* mineral in a closed tube.	**ZOISITE.**	$Ca_2(Al.OH)Al_2(SiO_4)_3$.	Grayish-white, green, pink.	Vitreous, pearly.	C. Pinac., *per.* F. Uneven.	6–6.5	3.25–3.35	3–4	Orthorh. U. prism.
		Clinozoisite.	$Ca_2(Al.OH)Al_2(SiO_4)_3$.	White to pale-pink.	Vitreous.	C. Basal, *per.* F. Uneven.	6–7	3.37	3–4	Monocl.
	Generally fuses to a blac . slag. Yields water like the foregoing.	**EPIDOTE.**	$Ca_2(Al.OH)(Al,Fe)_2(SiO_4)_3$.	Yellowish- to blackish-green, gray.	Vitreous	C. Basal, *per.* F. Uneven.	6–7	3.37–3.45	3–4	Monocl. Page 213.

DIVISION 5.—Concluded on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

B.—Fusible from 1-5, and Non-volatile, or only Slowly or Partially Volatile.

PART III.—With sodium carbonate on charcoal *do not give a metallic globule,* and when fused alone in the reducing flame *do not become magnetic.*

DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.—Concluded.

B.—Fusible from 1—5, and Non-volatile, or only Slowly or Partially Volatile.

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DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Fusibility.	Crystallization.
B. B. cracks, whitens, and fuses at 5–5½ to a white enamel.	In the closed tube at a red heat unchanged, but on *intense ignition* B. B. whitens and yields 6 per cent of water.	Euclase.	$Be(Al.OH)SiO_4$.	Pale-green or blue to white.	Vitreous, pearly.	C. Pinac., *per.* F. Uneven.	7.5	3.05–3.1	5–5.5	Monocl.
Fuse quietly or with but little intumescence. Characterized by a perfect prismatic cleavage at angles of 55° and 125°, which serves to distinguish these minerals from those of the next section. This section contains minerals of the **AMPHIBOLE GROUP.** The crystals usually have a prismatic habit, and are often divergent or inradiated-columnar aggregates. Isolated crystals are usually bladed or six-sided, vertically striated, and terminated by two planes (p. 212).	Fuses to a colorless or nearly colorless glass. Sometimes fibrous (*asbestiform*).	**TREMOLITE.** (Asbestus in part.)	$CaMg_3Si_4O_{12}$.	White, gray, violet.	Vitreous, pearly.	C. Prism., *per.* F. Uneven.	5–6	3.00	4	Monocl.
	Fuses to a greenish or brownish globule. Gives but little yellow coloration to the flame.	**ACTINOLITE.** (Nephrite or Jade, when compact.)	$Ca(Mg,Fe)_3Si_4O_{12}$.	Green of various shades.	Vitreous, pearly.	C. Prism., *per.* F. Uneven.	5–6	3–3.05	4	Monocl. Prismatic.
	Fuses to a dark, shiny globule. Generally intumesces slightly and colors the flame yellow (*sodium*). The color of the mineral deepens as the amount of iron increases.	**AMPHIBOLE.** **HORNBLENDE.**	$CaMg_3Si_4O_{12}$. $Na_2Al_2Si_4O_{12}$. $Mg_2Al_4Si_2O_{12}$. Fe iso. w. Mg & Al.	Green to black.	Vitreous.	C. Prism., *per.* F. Uneven.	5–6	3.2–3.3	3–4	Monocl. U. cryst. Page 212.
	Imparts a strong yellow color to the flame (*sodium*).	Glaucophane. See *riebeckite*, p. 270.	$Na_2Al_2Si_4O_{12}$. $Mg_4Si_4O_{12}$. Ca & Fe iso. w. Mg.	Lavender- to azure-blue.	Vitreous, pearly.	C. Prism., *per.* F. Uneven.	6–6.5	3.1	3–3.5	Monocl. U. mass.
Fuse quietly or with little intumescence. The prismatic cleavage, at angles of 87° and 93°, is not very pronounced, thus distinguishing these minerals from those of the foregoing group. This section contains minerals of the **PYROXENE GROUP.** The crystals usually exhibit the combination of a nearly rectangular prism, with truncated edges (p. 211). They often show a distinct basal parting (p. 225). The pyroxenes have a higher specific gravity than the corresponding members of the amphibole group.	Fuses to a colorless or nearly colorless glass.	**DIOPSIDE.**	$CaMgSi_2O_6$.	Colorless, white, pale-green.	Vitreous.	C. Prismatic. F. Uneven.	5–6	3.29	4	Monocl. U. cryst.
	Fuse to a greenish or brownish glass. Show variations in composition from Diopside to Hedenbergite, the color deepening as the amount of iron increases.	**PYROXENE.**	$Ca(Mg,Fe)Si_2O_6$.	Light to dark-green.	Vitreous.	C. Prismatic. F. Uneven.	5–6	3.1–3.5 U.3.3	4	Monocl. U. cryst. Page 211.
		Hedenbergite.	$CaFeSi_2O_6$.	Greenish-black to black.	Vitreous.	C. Prismatic. F. Uneven.	5–6	3.55	4	Monocl.
	Fuses to a shiny, black glass. Reacts for *aluminium* and *ferric iron*, p. 110, § 4. Often gives a yellow flame (*sodium*). ☞ Compare *Acmite* (p. 270).	**AUGITE.** (Common pyroxene of lavas and igneous rocks.)	$CaMgSi_2O_6$. $MgAl_2SiO_6$. $NaAlSi_2O_6$. Fe iso. w. Mg & Al.	Greenish-black to black.	Vitreous.	C. Prismatic. F. Uneven.	5–6	3.35–3.45	4–4.5	Monocl. Figs. 335 & 336. Page 212.
	Fuses to a transparent blebby glass, coloring the flame yellow (*sodium*). Usually in compact, exceedingly tough masses.	**Jadeite.** (Jade.)	$NaAlSi_2O_6$.	White, grayish, greenish.	Vitreous.	C. Prismatic. F. Splintery.	7	3.33	2.5	Monocl. U. mass.
Fuses with intumescence. Colors the flame yellow (*sodium*).	Gives 3½ per cent of water on intense ignition in the closed tube	Eudidymite.	$HNaBeSi_3O_8$.	White.	Vitreous, pearly.	C. Basal, *per.*	6	2.55	2.5–3	Monocl. U. tabul.
Soft, and has a greasy feel. Difficultly fusible.	Gives 4–5 per cent of water on intense ignition in the closed tube.	**TALC.** (Steatite, Soapstone.)	$H_2Mg_3(SiO_3)_4$.	Apple green, gray, white.	Pearly, greasy.	C. Basal, *per.*	1	2.80	5–5.5	Foliated. Compact.
Fuses quietly, and without marked flame coloration.	Contains both ferrous and ferric iron, and much calcium.	Babingtonite.	$(Ca,Fe,Mn)SiO_3$. $Fe_2(SiO_3)_3$.	Greenish-black to black.	Vitreous.	C. 1 direc., *per.* F. Uneven.	5.5–6	3.34–3.40	3–3.5	Triclinic. U. cryst.

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II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives an alkaline reaction when placed on moistened turmeric-paper.—In part.

C.—Infusible or Very Difficultly Fusible.

Division 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives an *alkaline reaction* when placed on moistened turmeric-paper.

N.B.—The minerals in this division are chiefly the salts of the *alkali earth metals, calcium, strontium,* and *barium,* with volatile acids.

Carbonates.—The powdered mineral *effervesces* or gives off *carbon dioxide gas* when treated in a test-tube with dilute hydrochloric acid (p. 62, §1). It is often necessary to warm the acid, in which case boiling must not be mistaken for effervescence.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
On intense ignition B. B. throws out fine branches and gives a crimson flame (*strontium*).	The rather dilute HCl solution gives a precipitate upon addition of a few drops of *dilute* H_2SO_4 (p. 117, §3).	**STRONTIANITE.**	$SrCO_3$.	White, gray, yellow, green.	Vitreous.	C. Prismatic. F. Uneven.	3.5–4	3.70	Orthorh. Column.
On intense ignition B. B. gives a yellowish-green flame (*barium*).	The dilute HCl solution gives a precipitate upon addition of a few drops of *dilute* H_2SO_4 (p. 52, §3). Crystals of Bromlite generally have a hexagonal aspect.	Barytocalcite.	$CaBa(CO_3)_2$.	White, gray, yellow, green.	Vitreous.	C. Prism., *per.* F. Uneven.	4	3.65	Monocl. Prismat.
		Bromlite.	$(Ca,Ba)CO_3$.	White, gray, cream-color.	Vitreous.	F. Uneven.	4–4.5	3.7	Orthorh. Pyramid.
B. B. swells and colors the flame intensely yellow (*sodium*).	Assumes a blue color when moistened with cobalt nitrate and intensely ignited (*aluminium*).	Dawsonite.	$Na(Al.2OH)CO_3$.	White.	Vitreous, silky.	F. Longitudinal.	3	2.40	Monocl. Radiated.
Contain *calcium.*—Dissolve 2 ivory-spoonfuls of the powdered mineral in 3 cc. of HCl (warmed if necessary). Divide into two parts, dilute one with 10 cc. of water, and add a few drops of *dilute* H_2SO_4 to each. The concentrated solution gives a precipitate of *calcium sulphate* (p. 59, §3), but no precipitate forms in the dilute solution, thus showing the absence of strontium and barium.	Imparts to the salt of phosphorus bead in R. F. a green color (*uranium*).	Uranothallite. (Liebigite.)	$Ca_2U(CO_3)_4.10H_2O$.	Yellowish-green.	Vitreous, pearly.	C. One direction.	2.5–3		Orthorh. Tabular.
	Gives much water in the closed tube. The dilute HCl solution gives a precipitate with barium chloride (p. 122, §1). See p. 273.	Thaumasite.	$CaCO_3.CaSiO_3.CaSO_4.15H_2O$.	White, colorless.	Vitreous.	F. Splintery.	3.5	1.87	Hexag. Fibrous.
	Fragments effervesce freely in *cold dilute* HCl. Crystals of aragonite fall to a powder (change to *calcite*) when heated below redness in a closed tube. Show marked differences in cleavage and specific gravity.	**CALCITE.** (Marble, Limestone.)	$CaCO_3$.	Colorless, white, and variously tinted.	Vitreous.	C. Rhombohedral, *per.*	3	2.72	Hex. Rh. Page 192.
		ARAGONITE.	$CaCO_3$.	Colorless, white, and variously tinted.	Vitreous.	C. Pinac., *poor.* F. Uneven.	3.5–4	2.95	Orthorh. Page 205.
	Fragments effervesce freely in *hot,* but not in cold, dilute HCl. Test for magnesium as directed on p. 91, §1, *b*.	**DOLOMITE.** (Pearl Spar.)	$CaMg(CO_3)_2$. Fe iso. w. Mg.	Colorless, white, and variously tinted.	Vitreous, pearly.	C. Rhombohedral, *per.*	3.5–4	2.85	Hex. Rh. Cl. 14, p. 219.
	B. B. becomes black and slightly magnetic. Gives a considerable reaction for iron when tested as directed on p. 91, §1, *b*.	**Ankerite.** (Ferriferous Dolomite.)	$Ca(Mg, Fe,Mn)(CO_3)_2$.	Brown, gray, seldom white.	Vitreous, pearly.	C. Rhombohedral, *per.*	3.5–4	2.95–3.1	Hex. Rh. Cl. 14, p. 219.
Contain *magnesium.*—Give a precipitate of *ammonium magnesium phosphate* when tested as directed on p. 91, §1, *b*.	Scarcely acted upon by cold, dilute HCl. Breunnerite gives a considerable reaction for iron when tested as directed on p. 91, §1, *b*.	**MAGNESITE.**	$MgCO_3$.	White, yellow, gray, brown.	Vitreous, pearly.	C. Rhombohedral, *per.*	3.5–4.5	3.0–3.1	Hex. Rh. U. gran.
		Breunnerite. (Ferriferous Magnesite.)	$(Mg,Fe)CO_3$.	Brown, gray, seldom white.	Vitreous.	C. Rhombohedral, *per.*	3.5–4.5	3.0–3.2	Hex. Rh.
With the exception of Magnesite and Breunnerite, these minerals give abundant water when heated in a closed tube. The magnesium minerals, when pure, do not give very decided alkaline reactions with turmeric-paper.	Fragments are scarcely acted upon by cold, dilute HCl.	Hydromagnesite.	$Mg_2(Mg.OH)_2(CO_3)_3.3H_2O$.	White.	Vitreous, silky.		3.5	2.15	Monocl. U. acic.
	Whitens, and alters to Nesquehonite on exposure to dry air.	Lansfordite.	$Mg_2(Mg.OH)_2(CO_3)_3.21H_2O$.	Colorless, white.	Paraffin-like.	C. Basal.	2.5	1.5–1.7	Triclinic.
	Occurs in spherical aggregations.	Hydrogioberite.	$(Mg.OH)_2CO_3.2H_2O$.	Light-gray.				2.16	Compact.
	Soluble in cold, dilute HCl.	Nesquehonite.	$MgCO_3.3H_2O$.	Colorless, white.	Vitreous.	C. Prism., *per.* F. Splinter	2.5	1.84	Orthorh. Prismat.

Some varieties of Siderite, $FeCO_3$, Rhodonite, $MnCO_3$, and Smithsonite, $ZnCO_3$ (Division 2) contain sufficient *calcium* to cause them to give an alkaline reaction after ignition.

Division 1.—Concluded on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives an alkaline reaction when placed on moistened turmeric-paper.—Concluded.

DIVISION 2.—Soluble in hydrochloric acid, but do not yield a jelly or a residue of silica upon evaporation.—In part.

C.—Infusible or Very Difficultly Fusible.

DIVISION 1.—After intense ignition before the blowpipe, either in the forceps or on charcoal, the ignited material gives an *alkaline reaction* when placed on moistened turmeric-paper.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Easily and quietly soluble in warm HCl. Gives the reaction for magnesium (p. 91, §1).	B. B. glows. Gives water in the closed tube. Yields only a slight alkaline reaction. Sometimes fibrous. ☞ Compare *Periclase* (p. 291).	**BRUCITE.**	$Mg(OH)_2$. Fe & Mn iso. w. Mg.	White, gray, green.	Pearly, vitreous.	C. Basal, *per.*	2.5	2.39	Hex. Rh. U. tabul.
Sulphates.—Give acid water in the closed tube, accompanied, after intense ignition, by the odor of sulphur dioxide (p. 123, § 3).	Ignited, then moistened with cobalt nitrate and again ignited, *assume* a blue color (*aluminium*). Kalinite is readily soluble in water, while alunite is scarcely attacked by acids.	**Kalinite.** (Potash Alum).	$KAl(SO_4)_2.12H_2O$.	Colorless, white.	Vitreous.	F. Conchoidal.	2–2.25	1.75	Isom. Pyr. U. fibrous.
		Alunite.	$(K,Na)(Al.2OH)_3(SO_4)_2$.	White, gray.	Vitreous.	C. Basal. F. Uneven.	3.5–4	2.83	Hex. Rh. U. tabul
Sulphide.—Soluble in HCl with evolution of hydrogen sulphide (p. 121, § 7). Found only in meteorites.		Oldhamite.	CaS.	Pale chestnut-brown.		C. Cubic.	4	2.58	Isometric.
Fluoride.—When intensely heated in the closed tube gives acid water and vapors which corrode the glass (p. 77, § 5). B. B. shows slight indication of fusion. Gives only a slight alkaline reaction.		Prosopite.	$CaF_2.2Al(F,OH)_3$.	Colorless, white, gray.	Vitreous.	C. Prismatic. F. Uneven.	4.5	2.89	Monocl.
Oxalate.—Quietly soluble in warm HCl. When heated below redness in a closed tube, crumbles, yields water and carbon monoxide gas, and changes to $CaCO_3$, which will effervesce with acids.		Whewellite.	$CaC_2O_4.H_2O$.	Colorless, white.	Vitreous.	C. Pinacoidal. F. Conchoidal.	2.5	2.23	Monocl.

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.

In order to determine that a mineral belongs to this division, treat one or two ivory-spoonfuls of the *finely powdered* material in a test-tube with from 3 to 5 cc. of hydrochloric acid, and boil until not over 1 cc. remains. The concentrated solution thus obtained should be a *clear liquid* (not thick and gelatinous, indicating a silicate, division 3), or in case any solid material separates from the solution or deposits on sides of the tube it should dissolve completely upon addition of water and warming.

Carbonates.—The powdered mineral *effervesces* or gives off *carbon dioxide gas* when treated in a test-tube with warm, dilute hydrochloric acid (p. 62, § 1). The absence of a disagreeable odor will serve to distinguish carbon dioxide from hydrogen sulphide, see beyond.	Contains *nickel.*—Imparts to the borax bead in O. F. a violet color when hot, changing to brown when cold. Gives water in the closed tube.		**Zaratite.** (Emerald Nickel.)	$(Ni.OH)_2CO_3.Ni(OH)_2.4H_2O$.	Emerald-green.	Vitreous.	F. Smooth.	3–3.25	2.6–2.7	Massive. Compact.
	Contains *manganese.*—Imparts to the borax bead in O. F. a reddish-violet color. Some varieties contain sufficient iron to cause them to become magnetic after heating B. B.		**RHODOCHROSITE.** (Dialogite.)	$MnCO_3$. Ca, Fe, Mg & Zn iso. w. Mn.	Rose-red, dark-red, brown.	Vitreous, pearly.	C. Rhombohedral, *per.*	3.5–4.5	3.45–3.60	Hex. Rh.
	Contain *zinc.*—Gives a *zinc flame*, and a coating of *zinc oxide* on charcoal, when heated as directed on p. 131, §1 (Fig 49).	Gives little or no water in the closed tube.	**SMITHSONITE.** (Dry-bone Ore.)	$ZnCO_3$. Ca, Mg, Fe, Mn & Co iso. w. Zn.	Brown, green, blue, pink, white.	Vitreous.	C. Rhombohedral, *per.* F. Uneven.	5	4.30–4.35	Hex. Rh. U. botry., Fig. 363.
		Give water in the closed tube. Aurichalcite gives an azure-blue flame (*copper*) when moistened with HCl and heated on charcoal B. B. (p. 72, § 1).	**Aurichalcite.**	$2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$.	Pale-green to blue.	Pearly.		2	3.6	Monocl. U. acic.
			Hydrozincite.	$2ZnCO_3.3Zn(OH)_2$?	White, gray, yellow.	Dull.		2–2.5	3.6–3.8	Earthy. Compact.
	Contain *cobalt.*—Impart to the borax bead a blue color.	Gives little or no water in the closed tube.	Sphærocobaltite.	$CoCO_3$.	Rose-red.	Vitreous.		4	4.0–4.13	Hex. Rh.
		Gives water in the closed tube.	Remingtonite.	Uncertain. Hydrated $CoCO_3$.	Rose-red.			Soft.		Earthy.
	Contain *iron.*—Become black and *magnetic* when heated B. B. React for *ferrous iron* with potassium ferricyanide (p. 85, § 4).	Give reactions for both *magnesium* and *iron* when tested as directed on p. 91, § 1, *b.* ☞ Compare *Ankerite* (p. 289).	**Breunnerite.** (Ferriferous Magnesite.)	$(Mg.Fe)CO_3$.	Brown, gray, seldom white.	Vitreous.	C. Rhombohedral, *per.*	3.5–4.5	3.0–3.2	Hex. Rh.
		Give slight or no reactions for magnesium and calcium when tested as directed on p. 91, § 1, *b.* Fus. = 5.5–6.	**SIDERITE.** (Spathic Iron.)	$FeCO_3$. Ca, Mg & Mn iso. w. Fe.	Brown of different shades.	Vitreous, pearly.	C. Rhombohedral, *per.*	3.5–4	3.85	Hex. Rh.
	Give reactions for the *rare-earth metals* (p. 65).	Give the reaction for fluorine (p. 76, § 3). ☞ Compare *Bastnäsite* (p. 297), which is slowly dissolved by HCl.	**Parisite.**	$Ca(CeF)_2(CO_3)_3$. Di & La iso. w. Ce.	Yellowish-brown, brown.	Vitreous, resinous.	C. Basal, *per.* F. Uneven.	4.5	4.36	Hexag. Pyram.
	Gives only a slight effervescence with HCl.	Gives reactions for *calcium* (p. 59, § 3) and for a *phosphate* (p. 102, § 1).	Dahllite.	$Ca_7(CO_3)(PO_4)_4.\frac{1}{2}H_2O$.	Pale yellowish-white.	Resinous.	F. Splintery.	5	3.05	Fibrous.
	Give the test for *magnesium*, when treated as directed on p. 91, § 1.	☞ Compare *magnesite* and other *magnesium carbonates* on p. 289, which give a faint alkaline reaction after ignition.	**MAGNESITE.**	$MgCO_3$.	White, yellow, gray, brown.	Vitreous, pearly.	C. Rhombohedral, *per.*	3.5–4.5	3.0–3.1	Hex. Rh. U. gran.

DIVISION 2.—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—Continued.

C.—Infusible or Very Difficultly Fusible.

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—Continued.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Sulphates.—The dilute HCl solution gives a precipitate upon addition of barium chloride (p. 122, § 1).—Most of the minerals in this section give strongly acid water and a distinct odor of sulphur dioxide when intensely heated in a closed tube (p. 123, § 3).	Imparts to the borax bead a blue color (*cobalt*).		Bieberite.	$CoSO_4.7H_2O$.	Flesh- to rose-red.	Vitreous.			1.92	Monocl. Incrust.
	Imparts to the borax bead in O. F. a violet color when hot, changing to brown when cold (*nickel*).		Morenosite.	$NiSO_4.7H_2O$.	Apple-green to greenish-white.	Vitreous.	C. Pinacoidal.	2	2.00	Orthorh. U. acic.
	Impart to the borax bead in O. F. a reddish-violet color (*manganese*)—Apjohnite and Dietrichite give an abundant precipitate of *aluminium hydroxide* when ammonia is added to the HCl solution. Ilesite and Dietrichite give a coating of *zinc oxide* when intensely ignited on charcoal in R. F.		Szmikite.	$MnSO_4.H_2O$.	White to pink.			1.5	3.15	Amorph. Botry.
			Mallardite.	$MnSO_4.7H_2O$.	Pink to white.					Monocl. U. fibrous.
			Ilesite.	$(Mn,Zn,Fe)SO_4.4H_2O$.	Green to white.					Monocl. ? Prismatic.
			Apjohnite.	$MnAl_2(SO_4)_4.24H_2O$.	White to pale rose.	Silky.		1.5	1.78	Monocl. ? U. fibrous.
			Dietrichite.	$(Zn,Fe,Mn)Al_2(SO_4)_4.22H_2O$.	Dirty-white to brownish-yellow.	Silky.				Monocl. ? U. fibrous.
	Imparts to the salt of phosphorus bead in O. F. a pale yellowish-green color, which is changed to a fine green in R. F. (*uranium*).		Johannite.	Uncertain. $(SO_4),U,Cu,H_2O$.	Emerald-green.	Vitreous.		2–2.5	3.19	Monocl. Tabular.
			Uranopilite.	$CaU_8S_2O_{31}.25H_2O$?	Yellow.				3.75–3.95	Velvety incrust.
	Contain *aluminium.*—First ignited, then moistened with cobalt nitrate, and again intensly ignited, *assume* a blue color (p. 42, § 1). ☞ Compare zincaluminite below.	Gives little or no water in the closed tube.	Alumian.	$(Al_2O)(SO_4)_2$.	White.	Vitreous.		2–3	2.75	Hex. Rh.? Massive.
		B. B. gives a violet flame (*potassium*). Kalinite is readily soluble in water. Löwigite is insoluble in water and difficultly soluble in HCl.	**Kalinite.** **(Potash Alum.)**	$KAl(SO_4)_2.12H_2O$.	Colorless, white.	Vitreous.	F. Conchoidal.	2–2.5	1.75	Isom. Pyr U. fibrous.
			Löwigite.	$K(Al.2OH)_3(SO_4)_2.1\frac{1}{2}H_2O$.	Straw-yellow.	Vitreous.	F. Conchoidal.	3–4	2.58	Massive.
		Gives the odor of ammonia when heated in a closed tube with lime (ignited calcite).	Tschermigite. (Ammonia Alum.)	$NH_4Al(SO_4)_2.12H_2O$.	Colorless, white.	Vitreous.	F. Conchoidal.	1–2	1.50	Isom. Pyr. U. fibrous.
		Soluble in water.	Alunogen.	$Al_2(SO_4)_3.18H_2O$.	White.	Vitreous, silky.		1.5–2	1.6–1.8	Monocl. U. fibrous
		Insoluble in water.	Aluminite.	$Al_2(OH)_4SO_4.7H_2O$.	White.	Dull.	F. Uneven.	1–2	1.66	Monocl. U. Renif
			Felsöbanyite.	$Al_2(OH)_4SO_4.2Al(OH)_3.5H_2O$.	White.	Pearly.	C. Perfect.	1.5	2.33	Orthorh. U. scales.
	Gives a coating of *zinc oxide* when intensely heated on charcoal in R. F.		Zincaluminite.	$Zn_6Al_6S_2O_{25}.18H_2O$.	White, bluish-white.			2.5–3	2.26	Hexag. U. tabular
			Goslarite.	$ZnSO_4.7H_2O$.	White.	Vitreous.	C. Pinac., *per.*	2–2.5	1.95–2.04	Orthorh. Acicular.

DIVISION 2.—Continued on next page.

(Page 293.)

II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—Concluded.

C.—Infusible or Very Difficultly Fusible.

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—Continued.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Sulphides. — Decomposed by warm HCl with evolution of *hydrogen sulphide gas*, which may be detected by its odor.	Give a coating of *zinc oxide* on charcoal (yellow when hot, white when cold) when heated as directed on p. 131, § 1 (Fig. 49).	**SPHALERITE.** (Zinc Blende.) See p. 252.	ZnS. Fe and often a small amount of Cd iso. w. Zn.	White, green, yellow, brown, black.	Resinous, adamantine.	C. Dodecahedral, *per.*	3.5–4	4.10	Isom. Tet. Page 175.
		Wurtzite.	ZnS.	Brown to brown-black.	Resinous.	C. Prismatic.	3.5–4	3.98	Hexag. Hemimor.
		Voltzite.	$4ZnS.ZnO$.	Rose-red, yellow, brown.	Vitreous, greasy.		4–4.5	3.65–3.80	Globular.
	Gives a reddish-brown coating of *cadmium oxide* when heated on charcoal in R. F. with a little Na_2CO_3.	**Greenockite.**	CdS.	Honey-, citron- or orange-yellow	Adamantine, resinous.	C. Prismatic. F. Uneven.	3–3.5	4.9–5.0	Hexag. Hemimor.
Contain *iron.*—When heated in R.F. become strongly magnetic. With the exception of Pyroaurite become black when heated B.B. and fuse when in fine splinters (Fus. = 5–6). Completely, though somewhat slowly, soluble in HCl. The solution is yellow, and, with the exception of Symplesite, reacts for *ferric iron* with potassium ferrocyanide (p. 85, § 4). ☞ Compare *Bunsenite* below, which also becomes magnetic.	Streak brownish-red (Indian-red, red-ocher). Hematite is anhydrous or nearly so. Turgite gives water (5 per cent) in the closed tube and generally decrepitates.	**HEMATITE.** Fig. 262. See p. 255.	Fe_2O_3.	Red to reddish-black.	Dull to sub-metallic.	F. Splintery.	5.5–6	4.9–5.2	Compact. Earthy.
		Turgite (Hydro-hematite.)	$Fe_4O_5(OH)_2 = 2Fe_2O_3.H_2O$.	Red to reddish-black.	Dull to sub-metallic.	F. Splintery.	5–6	4.14	Incrust. Mammill.
	Streak yellowish-brown (yellow-ocher). Give water in the closed tube.	**GOETHITE.** (Göthite.)	$FeO(OH) = 2FeO_3.2H_2O$.	Yellow, brown to brownish-black.	Dull to adamantine.	C. Pinac., *per.* F. Splintery.	5–5.5	4.37	Orthorh. Prismatic
		LIMONITE. (Brown Hematite, Bog Iron Ore.)	$Fe_4O_3(OH)_6 = 2Fe_2O_3.3H_2O$.	Yellow, brown to brownish-black.	Silky, dull, earthy.	F. Splintery.	5–5.5	3.6–4.0	Radiated. Stalactitic
		Xanthosiderite.	$Fe_2O(OH)_4 = 2Fe_2O_3.4H_2O$.	Golden-yellow to brown.	Silky, pitch-like, earthy.		2.5		Acicular. Earthy.
	Gives a decided reaction for magnesium after separation of the iron (p. 91, § 1, *b*).	Pyroaurite.	$Fe(OH)_3.3Mg(OH)_2.3H_2O$	Golden-yellow to silver-white.	Pearly.		2–3	2.07	Hexag. Tabular.
	Gives the reaction for an arsenate when intensely heated in a closed tube with splinters of charcoal (p. 51, § *a*).	Symplesite.	$Fe_3(AsO_4)_2.8H_2O$.	Blue to mountain-green.	Pearly, vitreous.	C. Pinac., *per.* F. Uneven.	2.5	2.95	Monocl. Prismatic
Contains *nickel.*—Colors the borax bead in O.F. violet when hot and brown when cold.	Magnetic after heating in R. F.	Bunsenite.	NiO.	Pistachio-green.	Vitreous.		5.5	6.40	Isometric.
Contain *manganese.*—Impart to the borax bead in O. F. a reddish-violet color which becomes colorless in R. F.	Gives a coating of zinc oxide when the *finely powdered mineral* is intensely heated B. B. on charcoal with a little Na_2CO_3.	**ZINCITE.** (Red Zinc Ore.)	$(Zn,Mn)O$.	Deep-red to orange-yellow.	Adamantine.	C. Basal, *per.*	4–4.5	5.5–5.55	Hexag. Hemimor Page 190.
	Gives a coating of oxide of antimony when heated with a little Na_2CO_3 on charcoal in R. F.	Manganostibite.	$Mn_{10}Sb_2O_5$. As iso. w. Sb.	Black.					Compact.
	Anhydrous. The color of the unaltered mineral is very characteristic. Darkens on exposure.	Manganosite.	MnO.	Dark emerald-green.	Vitreous, adamantine.	C. Cubic, *per.*	5–6	5.18	Isometric.
	Gives water in the closed tube. Color *white* when fresh, but darkens on exposure.	Pyrochroite.	$Mn(OH)_2$.	White to bronze.	Pearly.	C. Basal, *per.*	2.5	3.26	Hex. Rh. Tabular.
	Structure earthy, pulverulent and frothy. Gives water in the closed tube.	Wad. (Bog Manganese.)	Impure hydrated oxide of manganese.	Gray, brown, dull-black.	Dull.				Massive. Earthy.
	Give an *arsenical mirror* when intensely heated in a closed tube with Na_2CO_3 and charcoal powder (p. 51, § *b*).	Allactite.	$Mn_3(AsO_4)_2.4Mn(OH)_2$.	Brownish-red.	Vitreous, greasy.	C. One direc. F. Uneven	4.5	3.84	Monocl
		Hematolite.	$(Al,Mn)AsO_4.4Mn(OH)_2$.	Brownish- to garnet-red.	Vitreous, greasy.	C. Basal, *per.* F. Uneven.	3.5	3.35	Hex. Rh.
Contains *cobalt.*—Imparts to the borax bead a blue color.	Gives a green color to the Na_2CO_3 bead in O. F. (*manganese*). Gives water in a closed tube.	Asbolite.	Hydrated cobalt and manganese oxides.	Brown, black.	Dull.				Massive. Earthy.

DIVISION 2.—Concluded on next page.

(Page 293.)

II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—Concluded.

C.—Infusible or Very Difficultly Fusible.

DIVISION 2.—Soluble in hydrochloric acid, but *do not yield a jelly or a residue of silica* upon evaporation.—Concluded.

General Characters.		Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Phosphates.—When a few drops of the HNO_3 solution are added to ammonium molybdate a yellow precipitate of *ammonium phosphomolybdate* is thrown down (p. 102, § 1). The pale, *bluish-green* flame coloration (sometimes only seen after moistening the assay with H_2SO_4) may also be used to identify a phosphate.	Contain *calcium.*—The cold, concentrated HCl solution gives a precipitate of *calcium sulphate* upon addition of a few drops of *dilute* H_2SO_4 (p. 59, § 3).	Gives a slight reaction for fluorine (p. 75, § 1) and generally also for chlorine (p. 67, § 1).	**APATITE.**	$Ca_4(CaF)(PO_4)_3$. Cl iso. w. F.	Green, blue, violet, brown, colorless.	Vitreous, greasy.	C. Basal. F. Uneven.	5	3.15	Hexag. Page 189.
		Gives water in the closed tube.	Martinite.	$H_2Ca_5(PO_4)_4.\frac{1}{2}H_2O$.	White, yellow.				2.9	Hex. Rh.
	Contain *aluminium* and *water.*—The ignited minerals, when moistened with cobalt nitrate and intensely ignited B. B., *assume* a blue color (p. 42, § 1). Give water in the closed tube. When crystals are not available, quantitative determinations of some of the constituents will be needed in order to make a sure identification of these rare phosphates. ☞ Compare the insoluble or difficultly soluble phosphates on p. 296. It is probable that some of the minerals in this section are insoluble in HCl.	26.9 per cent of water.	Callainite.	$AlPO_4.2\frac{1}{2}H_2O$.	Apple- to emerald-green.			3.5–4	2.51	Massive. Wax-like.
		30.7 per cent of water.	Zepharovichite.	$AlPO_4.3H_2O$.	Greenish- to grayish-white.		F. Conchoidal.	5.5	2.37	Compact. Horn-like.
		34.0 per cent of water.	Minervite.	$AlPO_4.3\frac{1}{2}H_2O$.	White.					Massive.
		37.1 per cent of water.	Gibbsite.	$AlPO_4.4H_2O$.	White.					Massive. Foliated.
		13.5 per cent of water.	Augelite.	$Al_2(OH)_3PO_4$.	Colorless, white.	Vitreous, pearly.	C. Prism., *per.* F. Uneven.	4.5–5	2.70	Monocl.
		23.8 per cent of water.	Peganite.	$Al_2(OH)_3PO_4.1\frac{1}{2}H_2O$.	Dark- to light-green.	Greasy, vitreous.	F. Uneven.	3–3.5	2.50	Orthorh. Prismatic.
		29.4 per cent of water.	Fischerite.	$Al_2(OH)_3PO_4.2\frac{1}{2}H_2O$.	Grass- to olive-green.	Vitreous.		5	2.46	Orthorh.
		26.5 per cent of water.	Sphærite.	$Al_5(OH)_9(PO_4)_2.12H_2O$.	Light gray or blue.	Greasy, vitreous.	C. One direction.	4	2.53	Globular.
		42.0 per cent of water.	Evansite.	$Al_3(OH)_6PO_4.6H_2O$.	White, pale-yellow or blue.	Vitreous, wax-like.	F. Uneven.	3.5–4	1.94	Massive. Botryoid.
	Contain the *rare-earth metals* (p. 65).—The HCl solution, made nearly neutral with ammonia, gives an abundant white precipitate upon addition of ammonium oxalate. ☞ Compare *Monazite* (p. 296), which is difficultly soluble in HCl.		Rhabdophanite. (Scovillite.)	$(La,Di,Y,Er)PO_4.H_2O$.	Brown, pink, yellow, white	Greasy.	F. Uneven.	3.5	3.95	Massive. Mammill.
			Churchite.	$Ca_3Ce_{10}(PO)_{4\,12}.24H_2O$?	Smoke-gray, pinkish tone.	Vitreous, pearly.	C. One direc. F. Conchoidal.	3–3.5	3.15	Monocl. ? Radiated.
Contain *magnesium.*—Give a precipitate of *ammonium magnesium phosphate* when treated as directed on p. 91, § 1, *b.* Glow with a *brilliant white light* when intensely ignited B. B.		The dilute HCl solution gives with ammonia a precipitate of *aluminium hydroxide.* Has a greasy feel.	Hydrotalcite.	$Mg_3Al(OH)_6.3H_2O$.	White.	Pearly.	C. Basal, *per.*	2	2.05–2.09	Hexag. U. foliated
		Give little or no water in the closed tube.	Periclase.	MgO.	Colorless, gray, dark-green.	Vitreous.	C. Cubic, *per.*	5.5–6	3.7–3.9	Isometric.
		Gives abundant water in the closed tube. Sometimes fibrous.	**BRUCITE.**	$Mg(OH)_2$.	White, gray, green.	Pearly, vitreous.	C. Basal, *per.*	2.5	2.39	Hex. Rh. U. tabular
Contain the *rare-earth metals.*—Test as directed on p. 65. ☞ Compare *Bastnäsite* (p. 297), which is slowly attacked by HCl.		In the closed tube at a high temperature give water which has a strong acid reaction (*fluorine,* p. 77, § 5).	Fluocerite.	$(Ce,La,Di)_2OF_4$. (OH) iso. w. F.	Reddish-yellow.	Resinous.	F. Uneven.	4	5.7–5.9	Hexag. U. mass.
			Yttrocerite.	$(Y,Er,Ce)F_3.5CaF_2.H_2O$.	Violet, gray, brown, white.	Vitreous, pearly.	C. Two direc. F. Uneven.	4–5	3.35–3.45	Massive.
Contains *uranium.*—Imparts to the salt of phosphorus bead in O. F. a pale yellowish-green color, which is changed to emerald-green in R. F.			Gummite.	$(Pb,Ca,Ba)U_3SiO_{12}.5H_2O$?	Yellow, orange-red to brown.	Greasy.	F. Uneven.	2.5–3	3.9–4.2	Massive. Gum-like.

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II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

Division 3.—Soluble in hydrochloric acid, and yield *gelatinous silica* upon evaporation.

C.—Infusible or Very Difficultly Fusible.

Division 3.—Soluble in hydrochloric acid, and yield *gelatinous silica* upon evaporation.

In order to determine that a mineral belongs in this division, treat one or two ivory-spoonfuls of the *finely powdered* material in a test-tube with from 3 to 5 cc. of hydrochloric acid and boil until not over 1 cc. remains. The mineral should go wholly into solution, unless difficultly soluble, and when the volume becomes small the contents of the tube should *thicken*, owing to the separation of *gelatinous silicic acid* (p. 108, § 1). The silicic acid thus separated will not go into solution when heated with additional water or acid.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Contain *zinc*.—Give a coating of *oxide of zinc* when heated with a little Na_2CO_3 on charcoal, or as shown in Fig. 49 (p. 131).	Gives little or no water in the closed tube.	**WILLEMITE.** See *troostite*, p. 279.	Zn_2SiO_4.	Colorless, white, green, yellow, blue.	Vitreous.	C. Basal, & prismatic. F. Uneven.	5.5	4.0–4.1	Hex. Rh. Page 196.
	Gives water in the closed tube. Exhibits pyro-electricity (p. 231).	**CALAMINE.** (Hemimorphite.)	$(Zn.OH)_2SiO_3$.	White, pale-green or blue.	Vitreous.	C. Prism., *per.* F. Uneven.	4.5–5	3.45	Orthorh. Page 207.
	Gives a slight odor of hydrogen sulphide when dissolved in HCl.	Danalite. See p. 269.	$R_5(R_2S)(SiO_4)_3$. $R = Zn, Be \& Fe$.	Pale rose-red to brownish.	Vitreous, resinous.	F. Uneven.		3.64	Isom. Tet.
Contains *copper*.—Gives a globule of copper when fused B. B. with Na_2CO_3 on charcoal.	Gives water in the closed tube.	**Dioptase.**	H_2CuSiO_4.	Emerald-green	Vitreous.	C. Rhomb., *per.* F. Conchoidal.	5	3.35	Hex. Rh. Page 196.
Contain *magnesium*. — Rather slowly decomposed by HCl. Treat ½ ivory-spoonful of the *finely powdered* material in a test-tube with 3 cc. of HCl and evaporate to dryness. Then add 3 cc. of HCl, a drop of HNO_3, 5 cc. of water, boil and filter. To the filtrate add ammonia to precipitate the iron, filter, and then test the filtrate with ammonium oxalate to prove the *absence* of calcium (p. 60, § 6) and with sodium phosphate to prove the *presence of magnesium* (p. 91, § 1, *b*).	Anhydrous. Contains little or no iron.	Forsterite.	Mg_2SiO_4.	White, gray, yellowish-white.	Vitreous.	C. Pinacoidal. F. Uneven.	6.5–7	3.24	Orthorh.
	Anhydrous. Contains a little iron (5 to 15 per cent FeO, rarely more). ☞ Compare *Hortonolite* (p. 269).	**CHRYSOLITE.** (Olivine, Peridot.)	$(Mg,Fe)_2SiO_4$.	Olive- to grayish-green, brown.	Vitreous.	C. Pinacoidal. F. Uneven.	6.5–7	3.27–3.37	Orthorh. Page 204.
	Give a little water when intensely ignited in a closed tube. Generally give reactions for fluorine (p. 76, § 2) and iron. These closely related minerals must be distinguished by differences in crystallization, or by means of a quantitative chemical analysis.	Prolectite.	$Mg[Mg(F,OH)]_2SiO_4$.	Brownish-gray		F. Uneven.			Monocl.
		Chondrodite.	$Mg_3[Mg(F,OH)]_2(SiO_4)_2$.	Brownish-red, yellow, white	Vitreous.	C. Basal. F. Uneven.	6–6.5	3.15–3.25	Monocl.
		Humite.	$Mg_5[Mg(F,OH)]_2(SiO_4)_3$.	Brownish-red, yellow, white.	Vitreous.	C. Basal. F. Uneven.	6–6.5	3.18–3.25	Orthorh.
		Clinohumite.	$Mg_7[Mg(F,OH)]_2(SiO_4)_4$.	Brownish-red, yellow, white.	Vitreous.	C. Basal. F. Uneven.	6–6.5	3.18–3.25	Monocl.
Contain *aluminium*. — When treated as directed in the foregoing paragraph ammonia produces a precipitate of *aluminium hydroxide*. Distinguished by their specific gravity from the heavier minerals in the following section.	Crumbles when heated B. B. Yields much water when heated in a closed tube.	**Allophane.**	$Al_2SiO_5.5H_2O$.	Colorless, yellow, green, blue.	Vitreous, wax-like.	F. Conchoidal.	3	1.88	Amorph.
	Gives little or no water in the closed tube. Fus. = 5.	Gehlenite.	$(Ca,Mg,Fe)_3Al_2Si_2O_{10}$.	Grayish-green to brown.	Vitreous, resinous.	F. Uneven.	5.5–6	2.9–3.0	Tetrag.
Contain the *rare-earth metals*.—After separation of the silica the solution gives the reactions described on pp. 65 and 66.—The high specific gravity of these minerals is noticeable.	Essentially a *thorium silicate*. The water is supposed to be the result of alteration.	Thorite. (Orangite.)	$ThSiO_4$, containing water.	Orange-yell'w, brown, black.	Resinous, greasy.	C. Prismatic. F. Uneven.	4.5–5	4.8–5.2	Tetrag.
	Contains the metals of the *cerium group*. On intense ignition in the closed tube gives a little water (*hydroxyl*).	**Cerite.**	$(Ca,Fe)(CeO)(Ce_2.3OH)(SiO_3)_3$. La & Di iso. w. Ce.	Clove-brown, gray, red.	Dull, resinous.	F. Splintery, uneven.	5.5	4.85–4.9	Orthorh. U. mass.
	Contains the metals of the *yttrium group*. B. B. swells, cracks apart, and often glows. Gives little or no water in the closed tube.	**Gadolinite.**	$FeBe_2Y_2Si_2O_{10}$.	Black, greenish-black, brown.	Vitreous, greasy.	F. Conchoidal, splintery.	6.5–7	4.2–4.5	Monocl.
Contains *uranium*.—Gives with the salt of phosphorus bead in O. F. a yellowish-green and in R. F. a green color.	Gives water in the closed tube.	**Uranophane.**	$CaU_2Si_2O_{11}.5H_2O$.	Honey-, lemon- or straw-yellow.	Vitreous, silky.		2–3	3.8–3.9	Triclinic. U. acic.

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II. MINERALS WITHOUT METALLIC LUSTER

C.—Infusible or Very Difficultly Fusible.

DIVISION 4.—*Decomposed* by hydrochloric acid with the *separation of silica,* but without the formation of a jelly.

C.—Infusible or Very Difficultly Fusible.

DIVISION 4.—*Decomposed* by hydrochloric acid with the *separation of silica*, but without the formation of a jelly.

In order to determine that a mineral belongs in this division treat one or two ivory-spoonfuls of the *finely powdered* material in a test-tube with from 3 to 5 cc. of hyurochloric acid and boil until less than 1 cc. of acid remains. The behavior during this treatment should be carefully observed. When the powder is first shaken up with the cold acid the liquid will generally appear milky, owing to the fine, suspended material; when boiled, however, the liquid becomes translucent, although the separated silica prevents it from becoming perfectly clear. After a little experience one can usually decide from appearances whether the insoluble material is *separated silica* or the *undecomposed mineral;* in order to decide definitely, however, proceed as follows: Add a drop of nitric acid in order to oxidize any iron that may be present, dilute with 5 cc. of water, boil, and filter, when, if decomposition has taken place, the bases will be in the filtrate. Ammonia, added in excess to the solution, will precipitate aluminium and iron, which may be filtered off. In the strongly ammoniacal filtrate ammonium carbonate and sodium phosphate will precipitate calcium and magnesium, respectively, while if other bases are present (sodium, potassium, and lithium excepted) one or the other of the reagents previously mentioned will be very sure to produce a precipitate. For more complete details for testing for the bases see p. 110, § 4. There are some minerals which are slowly attacked by acids and give, consequently, slight precipitates of the bases when tests are made with ammonia, ammonium carbonate, and sodium phosphate; the minerals in this division, however, are *readily decomposed* by acids.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Contains *copper*.—Gives a globule of copper when a little of the mineral is heated with Na_2CO_3 on charcoal.	In the closed tube darkens and gives water.	**Chrysocolla.**	$CuSiO_3.2H_2O$?	Mountain-green to turquois-blue.	Vitreous, earthy.	F. Uneven.	2–4	2.0–2.4	Massive. Earthy.
Contains *nickel*.—Colors the borax bead in O. F. violet when hot and brown when cold.	In the closed tube blackens and gives water.	**Genthite.** (Garnierite.)	$H_4Ni_2Mg_2(SiO_4)_3.4H_2O$?	Pale- to deep-green.	Dull to resinous.	F. Uneven.	3–4	2.2–2.8	Amorph. Botryoid.
Contains *iron*.—B. B. becomes black and magnetic.	Give water in the closed tube. The iron is mostly *ferric* (p. 65, § 4).	Hisingerite.	Uncertain. Si, O. Fe''', Fe'', Mg, H_2O.	Black to brown-black.	Pitch-like, vitreous.	F. Conchoidal.	3	2.5–3.0	Amorph.
		Chloropal.	$H_6Fe_2(SiO_4)_3.2H_2O$?	Greenish-yellow, pistachio-green.	Wax-like.	F. Conchoidal, splintery.	2.5–4.5	1.7–1.9	Compact. Amorph.
Contain *magnesium*.—The HCl solution, if sufficiently dilute, gives no or only a slight precipitate with ammonia and ammonium carbonate, but gives an abundant precipitate with sodium phosphate (p. 91, § 1, *b*). ☞ Compare *Chondrodite* (p. 294).	Commonly in compact, greenish masses. Sometimes fibrous (Chrysotile, Fig. 360, p. 221) or foliated (Marmolite).	**SERPENTINE.** (Chrysotile, Serpentine-asbestus, Marmolite.)	$H_4(Mg,Fe)_3Si_2O_9$.	Olive to blackish-green, yellowish-green, white.	Greasy, wax-like.	F. Uneven, splintery.	2.5–5. U.4	2.5–2.65	Massive. Pseudomorphous (p. 220).
	Somewhat resembles a gum.	**Deweylite.** (Gymnite.)	$H_4Mg_4(SiO_4)_3.4H_2O$. Ni iso. w. Mg.	Yellow to apple-green.	Resinous.	F. Uneven, conchoidal.	3–4	2.40	Amorph.
	Compact, with fine earthy texture. Fus. = 5.	Sepiolite. (Meerschaum.)	$H_4Mg_2Si_3O_{10}$.	White to grayish-white.	Dull.	F. Uneven.	2–2.5	2.0	Compact. Earthy.
Contain *aluminium*.—The HCl solution gives an abundant precipitate with ammonia. Distinguished by their physical properties from the minerals in the following section.	Generally found in trapezohedrons (Fig. 105, p. 171) in lava. Reacts for potassium (p. 105, § 1, *c*).	**LEUCITE.**	$KAl(SiO_3)_2$. Na iso. w. K.	White, gray, colorless.	Vitreous.	F. Uneven, conchoidal.	5.5–6	2.45–2.50	Isometric. U. cryst.
	The HCl solution, filtered from the silica, gives with hydrochlorplatinic acid a cream-colored precipitate (*cæsium*, p. 58).	**Pollucite.**	$H_2Cs_4Al_4(SiO_3)_9$.	Colorless, white.	Vitreous.	F. Conchoidal.	6.5	2.98	Isometric. U. mass.
Contain the *rare earth metals*.—After separation of the silica the solution gives the reactions described on pp. 65 and 66.	Color the flame green when fused with the potassium bisulphate and fluorite mixture (*boron*, p. 56, § 1).	Melanocerite.	Uncertain. Si, Ta, B, Ce, La, Di, Y, Ca, Na, H, F.	Deep-brown to black.	Greasy, vitreous.	F. Conchoidal.	5–6	4.13	Hex. Rh.
		Caryocerite.	Uncertain. Si, Ta, B. Th. Ce, La, Di, Y, Ca, Na. H, F.	Nut-brown.	Greasy, vitreous.	F. Conchoidal.	5–6	4.29	Hex. Rh.

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II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 5.—Not belonging to the foregoing divisions.—*Insoluble in hydrochloric acid,* or only slightly acted upon.

Section a.—Hardness less than that of glass or a good quality of steel.—Can be scratched by a *knife.*—In part.

C.—Infusible or Very Difficultly Fusible.

DIVISION 5.—Not belonging to the foregoing divisions.—*Insoluble in hydrochloric acid*, or only slightly acted upon.

Section a.—Hardness less than that of glass or a good quality of steel.—Can be scratched by a *knife*.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Iron Ores.—B.B. in R.F. become strongly magnetic.	Compare the difficultly soluble oxides and hydroxides of iron on p. 292.	**IRON ORES.** (See p. 292.)	Oxides and hydroxides of iron.						
Structure *foliated* or *micaceous.*—Foliæ *tough* and *elastic.*	**THE MICAS.**—Difficultly fusible.	**MICAS.** (For varieties see p. 284.)	Silicates of H, K, Mg, Fe & Al.	White, yellow, brown, green, black.	Vitreous, pearly.	C. Basal, *eminent.*	2–3	2.8–3.0	Monocl.
Structure *foliated* or *micaceous.*—Foliæ *tough* and *flexible*, but *not elastic.* ☞ Compare *Talc*, beyond.	On intense ignition B. B. in the closed tube give considerable water. See p. 284.	**CLINOCHLORE.*** (Chlorite, Ripidolite.)	$H_8Mg_5Al_2Si_3O_{18}$. Fe iso. w. Mg & Al.	Green of various shades, rarely white.	Vitreous, pearly.	C. Basal, *per.*	2–2.5	2.65–2.75	Monocl.
	Color *reddish.*—Reacts like the foregoing, but imparts to the borax bead in R. F. a green color (*chromium*).	Kämmererite. (Chrom-clinochlore.)	$H_8Mg_5(Al,Cr)_2Si_3O_{18}$.	Garnet to peach-blossom-red.	Vitreous, pearly.	C. Basal, *per.*	2–2.5	2.65–2.75	Monocl.
	B. B. becomes black and magnetic.	Prochlorite.	$H_{40}(Fe,Mg)_{23}Al_{14}Si_{13}O_{90}$?	Green to blackish-green	Vitreous, pearly.	C. Basal, *per.*	1–2	2.78–2.95	Monocl.
Structure *foliated* or *micaceous.*—Foliæ *brittle* (Brittle Micas.)	Distinguished by differences in color.	**Seybertite.** (Clintonite.)	$H_3(Mg,Ca)_5Al_5Si_2O_{18}$.	Reddish-brown, copper-red.	Pearly.	C. Basal, *per.* F. Uneven.	4–5	3.0–3.1	Monocl.
		Xanthophyllite.	$H_8(Mg,Ca)_{14}Al_{16}Si_5O_{52}$.	Light-green.	Vitreous, pearly.	C. Basal, *per.*	4–5	3.0–3.1	Monocl.
Very soft, and have a *greasy feel.*—Give a little water (5 per cent) on intense ignition in a closed tube. ☞ Compare *Kaolinite*, beyond.	Ignited, then moistened with cobalt nitrate and again ignited *assumes* a blue color (*aluminium*). Often exfoliate prodigiously when heated B. B.	**PYROPHYLLITE.** (Agalmatolite.)	$H_2Al_2(SiO_3)_4$.	White, apple-green, gray, brown.	Pearly.	C. Basal, *per.*	1–2	2.8–2.9	Foliated. Compact.
	Does not give the foregoing reaction for aluminium.	**TALC.** (Steatite, Soapstone.)	$H_2Mg_3(SiO_3)_4$.	Apple-green, gray, white.	Pearly, greasy.	C. Basal, *per.*	1	2.80	Foliated Compact
Sulphates.—Give strongly acid water and the odor of sulphur dioxide, when intensely heated in a closed glass tube.	Ignited, then moistened with cobalt nitrate and again ignited, *assume* a blue color (*aluminium*). Alunite must be heated nearly to redness before it gives water. Löwigite parts with some of its water at a low temperature.	**Alunite.**	$(K,Na)(Al.2OH)_3(SO_4)_2$.	White, gray.	Vitreous.	C. Basal. F. Uneven.	3.5–4	2.83	Hex. Rh. U. tabul.
		Löwigite.	$K(Al.2OH)_3(SO_4)_2.1\frac{1}{2}H_2O$.	Straw-yellow.	Vitreous.	F. Conchoidal.	3–4	2.58	Massive.
Phosphates.—Decompose by fusion with Na_2CO_3, as directed on p. 110, § 4, then dissolve in HNO_3 and test the solution by adding a few drops of it to ammonium molybdate (p. 102, § 1). The pale bluish-green flame will often serve to indicate a phosphate (p. 102, § 2).	Contain the *rare-earth metals.*—Decompose an ivory-spoonful of the *finely powdered* mineral by heating in a test-tube with from 4 to 6 drops of *concentrated* H_2SO_4. After cooling, dilute with 10 cc. of water, filter if necessary, and add ammonium oxalate, when a precipitate of the *rare-earth metals* will be formed (pp. 65 and 66).	**Monazite.**	$(Ce,La,Di)PO_4$, often with $ThSiO_4$.	Yellowish- to reddish-brown.	Resinous.	Parting basal. F. Uneven.	5–5.5	5.2–5.3	Monocl.
		Xenotime.	YPO_4. Ce & Er iso. w. Y.	Yellowish- to reddish-brown	Resinous, vitreous.	C. Prism., *per.* F. Uneven.	4–5	4.55–5.1	Tetrag.
	Contain *calcium.*—Decompose by fusion with Na_2CO_3, as directed on p. 110, § 4, and dissolve in HCl or HNO_3. Add ammonia to the solution until a precipitate forms, then HCl, a drop at a time, until the liquid becomes clear, dilute to a volume of 10 cc. and add ammonium oxalate, which will precipitate *calcium oxalate* (p. 60, § 6). Svanbergite reacts for a sulphate (p. 122, § 1).	Tavistockite.	$Ca_3Al_2(OH)_6(PO_4)_2$.	White.	Pearly.				Acicular.
		Goyazite.	$Ca_3Al_{10}P_2O_{23}.9H_2O$.	Yellowish-white.		C. Basal.	5	3.26	Hexag. or tetrag.
		Svanbergite.	Uncertain. $(SO_4),(PO_4),Al,Ca,H_2O$.	Yellow, brown, rose-red.	Vitreous.	C. Basal, *per.*	5	3.3–3.5	Hex. Rh.
	Contain *aluminium.*—Ignited, then moistened with cobalt nitrate and again ignited, *assume* a blue color. Wavellite is usually in radiated, hemispherical or globular aggregates. ☞ Compare the phosphates on p. 293, some of which are undoubtedly difficultly soluble or insoluble in HCl.	**Wavellite.**	$(Al.OH)_3(PO_4)_2.5H_2O$. F iso. w. OH.	White, yellow, green, brown.	Vitreous, pearly.	C. Pinacoidal. F. Uneven.	3–4	2.33	Orthorh.
		Augelite.	$Al_2(OH)_3PO_4$.	Colorless, white.	Vitreous, pearly.	C. Prism., *per.* F. Uneven.	4.5–5	2.70	Monocl.
		Variscite.	$AlPO_4.2H_2O$.	Colorless, apple- to emerald-green.	Vitreous.		4	2.4	Orthorh. U. mass.
	Color blue. B. B. swells, loses its color and falls to pieces.	**Lazulite.**	$(Mg,Fe)(Al.OH)_2(PO_4)_2$.	Azure-blue.	Vitreous.	C. Prismatic. F. Uneven.	5–5.5	3.05–3.1	Monocl.

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* Amesite, Penninite, Corundophilite and other foliated minerals of the chlorite group are here included.

DIVISION 5. *Section a.*—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.

Section a.—Hardness less than that of glass or a good quality of steel.—Can be scratched by a *knife.*—Continued.

C.—Infusible or Very Difficultly Fusible.

Division 5.—*Insoluble in hydrochloric acid*, or only slightly acted upon.—Continued.

Section a. —*Hardness less than that of glass or a good quality of steel.*—Can be scratched by a *knife*.—Continued.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Contain *fluorine* and *water*.—When intensely heated in a closed glass tube yield acid water, and vapors which corrode the glass (p. 77, § 5).	Crystallizes in octahedrons.	Ralstonite.	$(Na_2,Mg)F_2.3Al(F,OH)_3.2H_2O$.	White to straw-yellow.	Vitreous.	F. Uneven.	4.5	2.58	Isometric.
	Crystallizes in pyramids.	Fluellite.	$AlF_3.H_2O$.	Colorless, white.	Vitreous.	F. Uneven.	3	2.17	Orthorh.
	B. B. whitens and shows slight indication of fusion. Gives with turmeric-paper a faint alkaline reaction.	Prosopite.	$Ca(F,OH)_2.2Al(F,OH)_3$.	Colorless, white, gray.	Vitreous.	C. Prismatic. F. Uneven.	4.5	2.89	Monocl.
Contain *fluorine and but little or no water*.—Give a deposit of silica when fused with potassium bisulphate in a closed tube of 6 mm. internal diameter (p. 76, § 2).	Heat the *finely powdered* mineral in a test-tube with from 4–6 drops of concentrated H_2SO_4. After cooling, add 10 cc. of water and test for the *rare-earth metals* with ammonium oxalate (p. 65). *Bastnäsite* effervesces slightly with HCl.	Tysonite.	$(Ce,La,Di)F_3$.	Wax-yellow to reddish-brown.	Vitreous, resinous.	C. Basal, *per.* F. Uneven.	4.5–5	6.13	Hexag.
		Bastnäsite.	$(RF)CO_3$. R = Ce, La & Di.	Wax-yellow to reddish-brown.	Vitreous, greasy.	F. Conchoidal.	4–4.5	4.9–5.2	Massive.
Contain *aluminium*.—*Assume* a blue color when moistened with cobalt nitrate and ignited B. B., but do not give the reactions of the preceding divisions.	Gives little or no water in the closed tube, while the others give water.	**CYANITE.** (Disthène.)	Al_2SiO_5.	Blue, green, gray or white.	Vitreous, pearly.	C. Pinacoidal, *perfect.*	5–7 (p. 302.)	3.56–3.66	Triclinic. Page 217.
	Generally clay-like, compact or mealy. Gives a skeleton of silica in the salt of phosphorus bead (p. 112, § 5).	**KAOLINITE.*** (Porcelain Clay.)	$H_4Al_2Si_2O_9$.	White.	Pearly, dull.	C. Basal, *per.* F. Earthy.	2–2.5	2.6–2.63	Monocl.
	Wholly soluble in the salt of phosphorus bead (*absence of silica*). Hydrargillite occurs generally as an incrustation or stalactitic, rarely crystallized; Bauxite generally in rounded or concretionary grains.	**Hydrargillite.** (Gibbsite.)	$Al(OH)_3$.	White.	Pearly, vitreous, dull.	C. Basal.	2.5–3.5	2.3–2.4	Monocl.
		Bauxite. (Aluminium Ore.)	$Al_2O(OH)_4$.	White, gray, yellow, red.	Dull, earthy.			2.55	Massive. Clay-like.
Contains *nickel*.—Imparts to the borax bead in O. F. a violet color when hot, brown when cold.	In the closed tube blackens and gives water (see p. 295).	**Genthite.** (Garnierite.)	$H_4Ni_2Mg_2(SiO_4)_3.4H_2O$?	Pale- to deep-green.	Dull to resinous.	F. Uneven.	3–4	2.2–2.8	Amorph. Botryoid.
Contain *antimony*.—Give globules of the metal and a coating of its oxide when heated in R. F. with Na_2CO_3 on charcoal. ☞ Compare *Lewisite*, *Manzeliite* and other antimony minerals on p. 263, and *Atopite*, p. 298.	Gives water in the closed tube.	Stibiconite.	$Sb_2O_4.H_2O$.	Pale yellow to yellowish-white.	Pearly, earthy.		4–4.5	5.1–5.3	Massive. Compact.
	Occurs in acicular crystals and as an incrustation.	Cervantite.	Sb_2O_4.	White to yellow.	Greasy, pearly.		4–5	4.08	Orthorh.? Acicular.
	Becomes magnetic after heating B. B.	Tripuhyite.	$Fe_2Sb_2O_7$?	Greenish-yellow.	Resinous.			5.82	Massive.
	Characterized by containing tantalum, p. 123.	Stibiotantalite.	$Sb(Ta,Nb)O_4$.	Pale-reddish- to greenish-yellow.	Adamantine.	Conchoidal.	5	6.5–7.4	Orthorh.?
Contains *zinc*.—Test as directed on p. 131 (Fig. 49).	Rather slowly acted upon by hot HCl, with evolution of hydrogen sulphide.	**SPHALERITE.** See p. 292.	ZnS. Fe and rarely Cd iso. w. Zn.	Brown, yellow, green, white.	Resinous, adamantine.	C. Dodecahedral, *perfect.*	3.5–4	4.10	Isom. Tet. Page 175.
Contain *titanium*.—Fused with borax, then dissolved in HCl and boiled with tin, the solution becomes violet (p. 127, § 2). ☞ Compare *Pyrochlore*, next page.	When fused with the bisulphate of potash and fluorite mixture, momentarily colors the flame green (*boron*, p. 56, § 1).	Warwickite.	$(Mg,Fe)_4TiB_2O_9$?	Hair-brown, dull-black.	Vitreous, dull.	C. Pinac., *per.* F. Uneven.	3–4	3.36	Orthorh.
	After precipitating titanium from the HCl solution with ammonia and filtering, the filtrate will react for calcium with ammonium oxalate.	**Perovskite.** See *dysanalyte*, p. 257.	$CaTiO_3$.	Yellow, orange, brown, black.	Adamantine.	C. Cubic. F. Uneven.	5.5	4.03	Isometric.
	Turmeric-paper assumes an orange color when placed in the HCl solution (*zirconium*, p. 133).	**Zirkelite.**	$(Ca,Fe,UO_2)(Zr,Ti)_2O_5$.	Black.	Resinous.	F. Conchoidal.	5	4.71	Isometric.

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* Halloysite, Newtonite, Cimolite, Montmorillinite, Collyrite and Schrötterite are closely related *Kaolin-like* minerals, with varying proportions of water, and, in some cases, of uncertain chemical composition.

Division 5, *Section a.*—Concluded on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.

Section a.—Hardness less than that of glass or a good quality of steel.—Can be scratched by a *knife.*—Concluded.

Section b.—Hardness equal to or greater than that of glass.—Can *not* be scratched by a *knife.*—In part.

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II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 5.—*Insoluble in hydrochloric acid*, or only slightly acted upon.

Section b.—Hardness equal to or greater than that of glass.—Can *not* be scratched by a *knife.*—Continued.

C.—Infusible or Very Difficultly Fusible.

Division 5.—*Insoluble in hydrochloric acid*, or only slightly acted upon.—Continued.

Section b.—Hardness equal to or greater than that of glass.—Can *not* be scratched by a *knife*.—Continued.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Leave an *insoluble skeleton of silica* when the *finely pulverized* minerals are fused B. B. in the salt of phosphorus bead (p. 112, § 5).	Imparts a green color to the salt of phosphorus bead (*chromium*).	**Uvarovite.** (Calcium-chromium Garnet.)	$Ca_3Cr_2(SiO_4)_3$. Al iso. w. Cr.	Emerald-green	Vitreous.	F. Conchoidal.	7.5	3.4–3.5	Isometric. Fig. 97.
	B. B. turns black. Reacts for sulphur (p. 122, § 2).	Melanophlogite.	Uncertain. SiO_2 with SO_3 and H_2O.	Colorless to light-brown.	Vitreous.		6.5–7	2.02	Isometric. Cubes.
	Gives strongly acid water in the closed tube. Assumes a blue color when ignited with cobalt nitrate (*aluminium*).	Zunyite.	$[Al.2(OH,F,Cl)]_6Al_2(SiO_4)_3$.	Colorless, white, gray.	Vitreous.	F. Uneven.	7	2.88	Isom. Tet. Tetrahedrous.
Gives globules of *tin* when fused B. B. on charcoal with Na_2CO_3 and charcoal powder (p. 125, § 1).	The high specific gravity is noticeable. ☞ Compare *Nordenskiöldine*, beyond.	**CASSITERITE.** (Tin Stone.)	SnO_2.	Brown to black. Rarely yellow or white.	Adamantine.	F. Uneven.	6–7	6.8–7.1	Tetrag. Page 180.
Fused with Na_2CO_3, then dissolved in HCl and boiled with tin, the solution assumes a violet color (titanium, p. 127, § 2). ☞ Rutile, octahedrite, and brookite (p. 300) furnish an interesting illustration of trimorphism.	Usually in prismatic crystals, often very slender and twinned.	**RUTILE.**	TiO_2.	Yellow, reddish-brown to black.	Adamantine.	C. Prismatic. F. Uneven.	6–6.5	4.18–4.25	Tetrag. Page 181.
	Distinguished from the foregoing by the habit of its crystals and by its different physical properties.	**Octahedrite.** (Anatase.)	TiO_2.	Yellow, brown, blue, black.	Adamantine.	C. Basal and pyramidal. F. Conchoidal.	5.5–6	3.8–3.95	Tetrag. Page 181.
Fuse B. B. in a Na_2CO_3 bead and dissolve in 1 cc. HCl and 1 cc. of water. A turmeric-paper placed in this solution assumes an orange color (*zirconium*, p. 133).	A small fragment when intensely heated B. B. glows and emits a white light. ☞ Compare *Baddeleyite* (p. 302).	**ZIRCON.** (Hyacinth.)	$ZrSiO_4$.	Colorless, gray, green, brown, red.	Adamantine.	C. Prismatic. F. Conchoidal.	7.5	4.68	Tetrag. Page 180.
Fused B. B. with borax, then dissolved in HCl and boiled with tin, the solution assumes a blue color (*niobium*, p. 99, § 1).	Fergusonite is essentially a niobate of yttrium, and sipylite a niobate of erbium. ☞ Compare the *niobates* (p. 300).	**Fergusonite.**	$(Y,Er,Ce)(Nb,Ta)O_4$.	Brownish-black.	Resinous, pitch-like.	F. Uneven.	5.5–6	4.3–5.8	Tetrag. Cl. 20, p. 219. U. mass.
		Sipylite.	$(Er,Ce,La,Di,H_3)NbO_4$?	Brownish-black.	Resinous.	F. Uneven.	6	4.9	Tetrag. U. mass.
Characterized by extreme hardness.—The transparent, colored varieties are highly prized as gem materials.	The *finely pulverized* mineral when made into a paste with cobalt nitrate and intensely heated B. B. on charcoal *assumes* a blue color (*aluminium*).	**CORUNDUM.** (Sapphire when blue, Ruby when red, Emery.)	Al_2O_3.	White, gray, yellow, brown, green, blue, pink, red.	Adamantine, vitreous.	Parting basal and rhombohedral. F. Uneven.	9	3.95–4.1	Hex. Rh. Page 194.
B. B. unaltered. Yields a clear glass when the *finely pulverized* mineral is mixed with an equal volume of Na_2CO_3 (rather less Na_2CO_3 than more), and a little of this mixture is fused B. B. in a small loop on platinum wire.—Give no reactions for the bases when tested as directed on p. 110, § 4. ☞ Compare *Chalcedony* and *Opal* (p. 302).	Crystallized generally in hexagonal prisms, terminated by rhombohedrons (p. 197). Amethyst is violet. Agate is compact, clouded, banded, and variously colored. Jasper is colored red or brown by hematite or limonite. Chert and Flint are compact, and vary in color from white or gray to black.	**QUARTZ.** (Rock Crystal, Amethyst, Agate, Jasper, Chert, Flint.)	SiO_2.	Colorless, white, smoky. Variously colored when impure.	Vitreous, greasy.	C. Rhombohedral, in traces. F. Conchoidal.	7	2.65–2.66	Hex. Rh. Page 197.
	Crystals are generally thin hexagonal plates, often twinned.	**Tridymite.**	SiO_2.	White, colorless.	Vitreous.	F. Conchoidal.	7	2.28–2.33	Hexag. Tabular.

Division 5, *Section b.*—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.

Section b.—Hardness equal to or greater than that of glass.—Can *not* be scratched by a *knife.*—Continued.

C.—Infusible or Very Difficultly Fusible.

Division 5.—*Insoluble in hydrochloric acid*, or only slightly acted upon.—Continued.

Section b.—*Hardness equal to or greater than that of glass.*—Can *not* be scratched by a *knife*.—Continued.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
B. B. unaltered. Does not give a clear glass with Na_2CO_3, when treated as directed in the foregoing paragraph.	Reacts for beryllium (p. 53, § *a*).	**Phenacite.**	Be_2SiO_4.	White, colorless.	Vitreous.	C. Prismatic. F. Conchoidal.	7.5–8	2.96	Hex. Rh. Page 196.
B. B. become milk-white, and at a high temperature show indications of fusion. Fus. = 5–6. Tourmaline exhibits pyroelectricity (p. 231).	Momentarily colors the blowpipe flame green (*boron*), when heated on platinum wire with the potassium bisulphate and fluorite mixture (p. 56, § 1).	**TOURMALINE.** (Achroite when colorless. Indicolite when blue, Rubellite when red.)	$R'_9Al_3(B.OH)_2Si_4O_{19}$. R'_9 replaced by Al, Fe″, Mg, Mn, Ca, Na, K, Li and H. F iso. w. OH.	Colorless, green, blue, pink, red.	Vitreous.	F. Conchoidal, Uneven.	7–7.5	3.0–3.1	Hex. Rh. Hemimor. Page 195.
	In the closed tube at a red heat unchanged, but on intense ignition B. B. whitens and yields about 2 per cent of water.	**BERYL.** (Aquamarine when pale green, Emerald when bright green.)	Approximately $Be_3Al_2(SiO_3)_6.\frac{1}{2}H_2O$.	Green, yellow, blue, pink, colorless.	Vitreous.	F. Conchoidal, Uneven.	7–7.5	2.7–2.75	Hexag. Page 188.
B. B. give a green flame (*boron*).	Gives globules of tin when fused B. B. on charcoal with Na_2CO_3 and charcoal powder (p. 125, § 1).	Nordenskiöldine.	$CaSn(BO_3)_2$.	Sulphur- to lemon-yellow.	Pearly, vitreous.	C. Basal, *per.* F. Conchoidal.	5.5–6	4.20	Hex. Rh. Tabular.
	Assumes a blue color when ignited with cobalt nitrate (*aluminium*).	Jeremejevite.	$AlBO_3$.	Colorless to pale yellow.	Vitreous.	F. Uneven.	6.5	3.28	Hexag. Prism.
Niobates.—Fused with borax, then dissolved in HCl and boiled with tin, the solution assumes at first a violet color (*titanium*), which changes on continued boiling to blue (*niobium*, p. 99, § 1). ☞ Compare the *Niobates*, pp. 254, 257, 298 and 299.	Distinguished with difficulty, and often only by studying the habit and angles of the crystals. Characterized by their dark color, resinous (pitch-like) luster and high specific gravity.	Æschynite.	Uncertain. Nb, Ti, Th, Ce, La, Ca, Fe, O.	Brownish-black to black.	Resinous.	F. Uneven, Conchoidal.	6	4.95–5.15	Orthorh.
		Euxenite.	Uncertain. Nb, Ti, Y, Er, Ce, U, Fe, H, O.	Brownish-black to black.	Resinous.	F. Uneven, Conchoidal.	6.5	4.6–5.0	Orthorh. U. mass.
		Polycrase.	Uncertain. Nb, Ti, Y, Er, Ce, U, Fe, H, O.	Brownish-black to black.	Resinous.	F. Conchoidal.	6	4.95–5.05	Orthorh.
Reacts for *titanium*, but not for niobium when tested as above.	Usually in tabular crystals. ☞ Compare *Rutile* and *Octahedrite* (p. 299).	**Brookite.**	TiO_2.	Hair-brown to black.	Adamantine.	F. Uneven.	6	4.0–4.08	Orthorh.
Usually has a blue color, but by transmitted light appears almost white when viewed in certain directions.	In the closed tube at a red heat unchanged, but on intense ignition B. B. yields about 1½ per cent of water.	**IOLITE.** (Cordierite.)	$H_2(Mg,Fe)_4Al_8Si_{10}O_{37}$.	Light or dark blue. Seldom colorless.	Vitreous.	C. Pinacoidal. F. Conchoidal.	7–7.5	2.61	Orthorh.
In prismatic crystals, commonly twinned (p. 205). Often very impure.	In the closed tube at a red heat unchanged, but on intense ignition B. B. yields about 2 per cent of water.	**STAUROLITE.**	$(AlO)_4(Al.OH)Fe(SiO_4)_2$. Fe iso. w. Al; Mg iso. w. Fe.	Red-brown to brownish-black.	Resinous, vitreous.	C. Pinacoidal. F. Uneven.	7–7.5	3.75–3.78	Orthorh. Page 205.
Reacts for boron (p. 56, § 2).	Gives water in the closed tube.	Hambergite.	$Be(Be.OH)BO_3$.	Grayish-white.	Vitreous.	C. Pinac., *per.*	7.5	2.35	Orthorh.
Gives a reaction for *fluorine* when heated in a bulb tube with sodium metaphosphate (p. 76, § 3).	The pulverized mineral when moistened with cobalt nitrate and intensely heated B. B. on charcoal assumes a blue color (*aluminium*).	**TOPAZ.**	$(AlF)_2SiO_4$. OH iso. w. F.	Colorless, yellow, pink, bluish, greenish.	Vitreous.	C. Basal, *per.* F. Uneven.	8	3.52–3.57	Orthorh. Page 204.

Division 5, *Section b.*—Continued on next page.

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II. MINERALS WITHOUT METALLIC LUSTER.

C.—Infusible or Very Difficultly Fusible.

DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.

Section b.—Hardness equal to or greater than that of glass.—Can *not* be scratched by *knife.*—Continued.

C.—Infusible or Very Difficultly Fusible.

DIVISION 5.—*Insoluble in hydrochloric acid*, or only slightly acted upon.—Continued.

Section b.—Hardness equal to or greater than that of glass.—Can *not* be scratched by a *knife.*—Continued.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Become black when heated B. B., and fuse when in very fine splinters, Fus. = 6.	Distinguished by differences in cleavage.—Anthophyllite occurs usually in slender prisms and is often fibrous.	**Anthophyllite.** (Asbestus in part.)	$(Mg,Fe)SiO_3$. H_2 iso. w. Mg.	Gray, clove-brown, green.	Vitreous, pearly.	C. Prism., *per.* Angles 54° & 126°.	5.5–6	3.10	Orthorh.
		ENSTATITE. (Bronzite.)	$(Mg,Fe)SiO_3$.	Gray, brown, green.	Pearly, bronze-like.	C. Prismatic. Angles 88° & 92°.	5.5–6.5	3.2–3.3	Orthorh.
	Becomes slightly magnetic after heating B. B.	**Hypersthene.**	$(Mg,Fe)SiO_3$.	Brownish-green to greenish-black	Pearly.	C. Pinac., *per.* F. Splintery.	5–6	3.3–3.5	Orthorh.
Characterized by the *absence of silica.* — The *finely powdered* minerals are wholly soluble in the salt of phosphorus bead (p. 112, § 5), and when made into a paste with cobalt nitrate and intensely ignited B. B. on charcoal, assume a blue color (*aluminium*).	Characterized by extreme hardness. Frequently occurs in twin crystals. Alexandrite is a variety which appears green by day, and red by lamplight.	**Chrysoberyl.** (Alexandrite.)	$BeAl_2O_4$.	Yellowish-, asparagus- to emerald-green	Vitreous.	C. Prismatic. F. Uneven, conchoidal.	8.5	3.65–3.8	Orthorh.
	Gives water in the closed tube.	**Diaspore.**	AlO(OH).	White, gray, yellowish, greenish.	Pearly, vitreous.	C. Pinac., *per.* F. Conchoidal.	6.5–7	3.35–3.45	Orthorh.
Silicates.—The finely powdered minerals are decomposed when fused in the salt of phosphorus bead, leaving a *skeleton of silica* (p. 112, § 5).—When made into a paste with cobalt nitrate and intensely ignited B. B. on charcoal, assume a blue color (*aluminium*). ☞ Compare *Cyanite* (p. 302).	In the closed tube at a red heat unchanged, but on *intense ignition* B. B. whitens and gives water. The color given by cobalt nitrate is more of a lavender than blue.	Bertrandite.	$Be_2(Be.OH)_2Si_2O_7$.	Colorless, white, yellow.	Pearly, vitreous.	C. Prismatic, basal, and pinac., *per.*	6–7	2.59–2.60	Orthorh. Hemimor.
	Occurs in fibrous or columnar aggregates. Contains magnesium (p. 110, § 4).	Kornerupine. (Prismatine.)	$Mg(AlO)_2SiO_4$. Fe iso. w. Mg.	White to yellowish-brown.	Vitreous.	C. Prismatic.	6.5	3.27–3.34	Orthorh.
	Occurs usually in stout, nearly rectangular prisms, with carbonaceous impurities disposed parallel to the axial directions of the crystals (Chiastolite). Often impure from partial alteration.	**ANDALUSITE.** (Chiastolite.)	Al_2SiO_5.	Flesh-red, reddish-brown, olive-green.	Vitreous.	C. Prismatic. F. Uneven.	7.5	3.16–3.20	Orthorh.
	Commonly fibrous, or in long slender crystals.	**SILLIMANITE.** (Fibrolite.)	Al_2SiO_5.	Hair-brown, gray, grayish green.	Vitreous.	C. Pinac., *per.* F. Uneven.	6–7	3.23–3.24	Orthorh.
	Whitens when heated in the closed tube. Gives the reaction for boron with turmeric-paper (p. 56, § 2).	Dumortierite.	$(AlO)_6Al_2(SiO_4)_3$? B iso. w. Al.	Deep-blue.	Vitreous.	C. Pinacoidal. F. Uneven.	7.	3.26–3.36	Orthorh.
B. B. cracks, whitens and fuses at 5½ to a white enamel.	In the closed tube at a red heat unchanged, but on intense ignition B. B. whitens and yields 6 per cent of water.	Euclase.	$Be(Al.OH)SiO_4$.	Colorless to pale green.	Pearly, vitreous.	C. Pinac., *per.* F. Conchoidal.	7.5	3.05–3.1	Monocl.
Gives a reaction for magnesium (p. 110, § 4).	Usually in disseminated grains.	Sapphirine.	$Mg_5Al_{12}Si_2O_{27}$.	Pale blue or green.	Vitreous.	F. Uneven.	7.5	3.42–3.48	Monocl.
In the closed tube at a high temperature yields water. May become slightly magnetic after heating B. B.	Crystals are usually tabular, with hexagonal outline.	Chloritoid.	$H_2(Fe,Mg)Al_2SiO_7$.	Dark gray, green, greenish-black.	Pearly, vitreous.	C. Basal, *per.*	6.5	3.52–3.57	Monocl.
		Ottrelite.	$H_2(Fe,Mg,Mn)(Al,Fe)_2Si_2O_9$.	Greenish-gray, black.	Vitreous.	C. Basal., *per.*	6–7	3.26	Monocl.

DIVISION 5, *Section b.*—Concluded on next page.

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C.—Infusible or Very Difficultly Fusible.

DIVISION 5.—*Insoluble in hydrochloric acid,* or only slightly acted upon.

Section b.—Hardness equal to or greater than that of glass.—Can *not* be scratched by a *knife.*—Concluded.

C.—Infusible or Very Difficultly Fusible.

Division 5.—*Insoluble in hydrochloric acid*, or only slightly acted upon.—Concluded.

Section b.—Hardness equal to or greater than that of glass.—Can *not* be scratched by a *knife*.—Concluded.

General Characters.	Specific Characters.	Name of Species.	Composition.	Color.	Luster.	Cleavage and Fracture.	Hardness.	Specific Gravity.	Crystallization.
Fuse B. B. in a Na_2CO_3 bead and treat with 1 cc. HCl and 1 cc. of water. A turmeric-paper placed in this solution assumes an orange color (*zirconium*, p. 133). Fusible B. B. on the thinnest edges.		Baddeleyite.	ZrO_2.	Colorless, yellow, brown, black.	Greasy, adamantine.	C. Basal.	6.5	5.5	Monocl.
Characterized by distinct cleavages in two directions at 90° or nearly 90° to one another.	Fusibility 5.	**THE FELDSPARS.** See Div. 5, p. 285.	Silicates of Al, K, Na & Ca.	White, gray, yellow, red.	Vitreous.	C. Basal & Pinacoidal.	6	2.55–2.80	Monocl. Triclinic.
Usually in bladed crystals.—Readily scratched by steel in the direction parallel to the cleavage, but harder than steel at right angles to the cleavage.	Assumes a **blue color** when moistened with cobalt nitrate and ignited (*aluminium*).	**CYANITE.** (Disthène.)	Al_2SiO_5.	Blue. At times white, gray, or green.	Vitreous, pearly.	C. Pinacoidal, *perfect*.	5–7	3.56–3.66	Triclinic. Page 217.
After fusion with Na_2CO_3 and dissolving in HNO_3 the solution gives the reaction for a phosphate with ammonium molybdate (p. 102, § 1).		Turquois. (Kallait.)	$H(Al.2OH)_2PO_4$. $(Cu.OH)'$ iso. w. $(Al.2OH)'$.	Blue, bluish-green, green.	Wax-like.	F. Uneven.	6	2.6–2.8	Massive.
Behave like quartz (page 299) when fused with Na_2CO_3 on platinum wire.	Anhydrous.—Structure botryoidal, stalactitic or incrusting. Carnelian is red, Chrysoprase green.	**CHALCEDONY.** (Carnelian, Chrysoprase.)	SiO_2.	White, gray, brown, blue, red, green.	Wax-like.	F. Uneven, splintery.	7	2.6–2.64	Massive.
	Give a little water upon intense ignition in the closed tube. Hyalite is colorless opal.	**OPAL.** (Hyalite.)	SiO_2 with water.	Colorless, red, yellow, green, blue, gray.	Vitreous, resinous.	F. Conchoidal.	5.5–6.5	2.1–2.2	Amorph.

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